THE

JOURNAL OF GEOLOGY

FEBRUARY–MARCH, 1906

THE FORMER LAND CONNECTION BETWEEN AFRICA AND SOUTH AMERICA

ERNEST H. L. SCHWARZ
Rhodes University College, Grahamstown, South Africa

There are two lines of inquiry which lead to a common conclusion, namely, that in former ages there was a notable land area where now the waters of the Atlantic lie. The first is concerned with the evidence afforded by islands in mid-ocean, and the second makes use of the character and conditions of deposition of the rocks on the continents bordering the ocean, and the distribution of animals now living on either side.

The bulk of the evidence is naturally accumulated in the second line of inquiry, because the continents are more accessible to observation and investigation; but even a little testimony from oceanic islands is of very great value, for these are formed by the piling-up of lavas, and the vents penetrate the ocean floor and bring up fragments of the solid crust beneath, so that we can actually handle and examine the constituent rocks of the submerged land.

In setting out the arguments on the first line of inquiry, it is necessary to define what is meant by a continental type of rock. Sir John Murray's list of continental types is gneiss, schist, sandstone, and compact limestone; and generally the term seems to be applied to any rock formed from the detritus of a land-mass, bearing in mind that it is generally accepted that sediments are deposited within two hundred miles of the coast. The inclusion of schists and gneisses seems to imply, in addition, that rocks may be included in the list of continental types which have been sub-

jected to deformation, the underlying idea being that earth-movements, such as those which produce mountain-folds, are confined to the regions of the globe that have been, or are, above the level of the ocean. The average specific gravity of continental types of rock is taken to be 2.68. We owe this term to the theory of Dana, Wallace, and others, that the oceans and continents have remained pretty much in the same places during geological time. The opposite of continental rock is, obviously, an oceanic rock, though this term is never actually used, the meaning being conveyed by various phrases, such as "the rocks forming the ocean floor," or "the sub-oceanic crust." Now, since the continents as a whole are less elevated above mean sea-level than the ocean floors are depressed below it, and since the density of water is less than half that of rock, it is obvious that if the densities of the continents and ocean floors were the same, the water would be attracted by the land-masses and heaped up along the shores. Such is actually assumed to be the case by Suess in the introduction to his *Antlitz der Erde*, but Fisher adduces very strong arguments in favor of the view that, setting aside rotational effects, the sea-level is sensibly spherical. In the latter case, the rocks of the sub-oceanic crust must be denser than the continental types to keep the water in place, and it is assumed that they are composed of basic original magma, and of basaltic flows from submarine volcanoes, which were more dense than the material of the continental crust.[1] The specific gravity of the rocks composing the ocean floor is taken to be 2.96. Thus it appears that in respect to the density of the sub-oceanic floor and the consequent form of its hydrosphere we have two rival schools, the one maintaining that the ocean surface forms a series of troughs between the continents, the other that the hydrosphere is sensibly spherical. This point must be settled before we can arrive at any comprehensive and satisfactory explanation of the geology of the earth as a whole; and, as far as I know, the materials at present available are not sufficient to enable one to give an irrefutable answer one way or the other. Even if Stokes, Pratt, and Faye, quoted by Fisher, go too far in one direction, and Fischer, Hann, and Listing, quoted by Suess, go too far

[1] Fisher, *Physics of the Earth's Crust*, chap. 25, and Appendix, p. 16.

in the other, yet the work of v. Drygalski[1] shows that there are factors which render both to a certain extent reconcilable. A great advance will have been made if it can be sufficiently proved that there was once a land surface where now the Atlantic Ocean or some notable part of it, lies; and I will now present the arguments n favor of this view.

Evidence from Ascension Island.—Ascension Island, like the Tristan group and St. Paul's rocks, lies in the mid-Atlantic ridge. Composed chiefly of volcanic rocks, there are abundant traces of the substructure being granitic in nature. Darwin states that in the neighborhood of the Green Mountain fragments of extraneous rocks are frequently met with imbedded in the midst of scoriæ.[2] Professor Renard confirms this, and mentions as occurring in this manner, granite, granitite, diabase, and gabbro, "torn up from the depths by eruptions."[3] There is no record of the granite basis appearing above the water-line; but if one takes these observations and considers them in the light that Woolnough has thrown on the Fiji Islands, another group which until recently had been thought to be purely volcanic, the true significance of these ejected blocks is made clear. In Fiji, Woolnough found that the whole group was underlain by a basis consisting of granite, quartz-diorite, quartzite, slates, and old sedimentary rocks of an indeterminate age,[4] and I confidently look to the results of his second expedition for affording still more striking evidence for the continental origin of these islands.

Evidence from St. Paul's rocks.—A great deal has been written on the ultra-basic rocks from this small mass of land in mid-ocean, and the opinions as to whether they are igneous or metamorphic have been equally balanced. The deformation of crystals imbedded in the matrix is such, however, that we must assume that the rock has been subjected to earth-movements, and in spite of the islands lying in a region of active submarine volcanic action, such a careful author as Neumayr was satisfied that this ultra-basic

[1] *Zeitschrift der Gesellschaft für Erdkunde* (Berlin, 1887).

[2] *Geological Observations on Volcanic Islands*, 1851, p. 40.

[3] Challenger Reports, *Physics and Chemistry*, Vol. II, Part 7, p. 62.

[4] *Proceedings of the Linnean Society of New South Wales*, 1903, Part 3.

rock—serpentine, peridotite, or sherzotite, whatever we choose to call it—was a metamorphic and not an eruptive rock.[1]

Evidence from Tristan d'Acunha.—In the Tristan d'Acunha group one block of gneiss was obtained by Mr. Hammond Tooke on a voyage thither in H. M. S. "Odin." Further specimens from Nightingale Island showed fragments of an earlier consolidated rock imbedded in a glassy matrix; the fragments were very minute and had the appearance of having been derived from a felsite or microgranite.[2] Both these cases would have been too small evidence on which to build any theory of the rock substructure of the islands, did not the description of Ascension Island support them. In Carmichael's account of the ascent of the peak on Tristan d'Acunha we read that the plain from which the central cone rises "is encumbered with large detached masses of porphyritic stone, and with others, inclosing crystals of sulphur or augite, which seem to have been ejected in their present state from the interior of the mountain."[3] Latter-day petrologists may smile at a man who cannot distinguish between crystals of sulphur and augite, but Carmichael was sound on general geological questions, and his description of Cape Town, with the sandstone resting on slate and granite with dolerite dykes,[4] is far better than many of the later accounts.

Volcanic ejectamenta as indices of deep-seated formations.—It is a remarkable fact that we can thus sample the deep-seated rocks, far below the zone of direct observation, by the ejectamenta of volcanoes. In South Africa I have made use of them in the Drakensberg, where many thousands of feet of Permian, Triassic, and perhaps Jurassic strata lie upon an Archæan base,[5] and in the central Karroo portions of the Palæozoic floor are brought to the surface in this manner. Often enough, in South Africa especially,

[1] *Erdgeschichte* (Leipzig, 1890), p. 199.

[2] *Transactions of the South African Philosophical Society*, Vol. XVI (Cape Town, 1905), p. 49.

[3] *Transactions of the Linnean Society*, Vol. XII (London, 1817), p. 491.

[4] Biographical sketch, *Hooker's Botanical Miscellanies*, Vol. II (London, 1831), pp. 1–59, 259–89.

[5] "The Volcanoes of Matatiele," *Annual Report of the Geological Commission* (Cape Town, 1902), p. 39.

the fragments torn from the throats of volcanic pipes have been rounded by attrition, and assume the characteristics of water-worn bowlders. In crush-breccias at Kuysna I have found rounded bowlders of exactly the same shape formed on the very spot from which they have been broken. The accounts of crush-breccias from the Isle of Man and Canada bear out the same view, namely, that rock-fragments can be rounded by simple dry friction. This point is important as the presence of apparently water-worn bowlders in volcanic agglomerates, such as those of the Kimberly diamond pipes, has frequently been adduced as evidence of water-action.

The comparative coolness of these volcanic eruptions is remarkable, and is such that in some cases, where fossiliferous strata contribute to the fragments in the volcanic pipe, the structure of the remains are as fresh as in the parent rock. In Scotland Sir A. Geikie records a vent at Elie Neck in which there are fragments of crinoidal limestone which show no trace of metamorphism, and their crowded organisms are as clearly recognizable as in pieces of limestone from a quarry.[1] In Kimberly the fragments of shale in the blue mass are quite fresh, and blocks containing fossil fish are as unaltered as if they had been procured from their original resting-place.

The temperature, however, was greater in other cases; for instance, Branco records blocks of middle Lias marly clay from the agglomerate in the Schleursbach volcano in Swabia, which have been baked and the included belemnites turned to white marble.[2] In the far south, Phillipi[3] describes blocks of granite entangled in lava on the top of the Saussberg; the ferro-magnesian minerals are melted, and the lava occupies the space they once filled by a sort of pseudomorphism, while the quartz and felspar remain intact. These blocks may have been derived from the surface of the ice-cap which once extended over the Saussberg, but the prolonged heating of the blocks, sufficient to melt

[1] "Geology of Eastern Fife," *Memoirs of the Geological Survey of Scotland* (Glasgow, 1902), p. 241.

[2] *Swabiens 125 Vulcan-Embryonen* (Stuttgart, 1894), p. 546.

[3] *Veröffentlichungen des Instituts für Meereskunde*, Heft 5, 1903, p. 126.

the hornblende, seems rather to indicate that the blocks came up in the lava from below.

I cannot forbear in this connection from drawing attention to a similar result which was obtained in the earliest experimental work which was carried out on the melting-points of rocks. Sir J. Hall, in heating some blocks of basalt from Arthur's Seat, near Edinburgh, found that at 100° of Wedgwood's pyrometer the whole was changed to a pure black glass, but at 60° the felspar remained unchanged while the hornblende disappeared, and formed a glass along with the basis of the stone.[1]

The further action of heat in volcanoes is shown in the Nightingale rocks, where fragments have been included in the liquid magma and in part remelted. And a still further stage, possibly, is exhibited in the rocks of Tristan d'Acunha, where sphene occurs in great abundance.[2] This mineral, together with perovskite, occurs in certain eruptive rocks, which, as far as I have observed them personally, suggest that sedimentary rocks have been absorbed in the molten magma. Perovskite is an accessory mineral in the melilite basalts of the Karroo volcanic pipes, and also in the mass of melilite basalt which occurs in the faulted Cretaceous rocks of the south coast of the Cape Colony;[3] it can be regarded, in fact, as an alteration product of the ilmenite in the original magma, from being brought into contact with limestone in the zone of intense pressure. The extraordinary abundance of sphene in the Tristan d'Acunha rocks I am inclined to view as the result of the interaction of a rock magma containing titanium acid and a limestone.

The final stage of the temperature gradient is that in which the rock is entirely molten, and the molecules of the various elements left to sort themselves into groups to form minerals without any influence from the inclusion of extraneous solid materials. If we could know the whole history of igneous rocks, perhaps these too might tell us something about the substructure of the earth beneath the volcanic vents, for it is not an entirely untenable theory that

[1] "Experiments on Whinstone and Lava," *Transactions of the Royal Society* (Edinburgh, 1798).

[2] *Transactions of the South African Philosophical Society*, Vol. XVI, p. 46.

[3] *Annual Report of the Geological Commission*, 1898, p. 62; *ibid.*, 1903, pp. 43–67.

they are derived from the fusion of pre-existing rocks, sedimentary and otherwise, which have been subjected to dynamical stress.

I have spoken hitherto mostly of the large fragments torn off from the throat of the volcano, but the inclusions in the Nightingale rock are more of the nature of fine dust. Such volcanic dust aggregated into beds would be known as a tuff, but it has not been generally recognized till recently that such tuffs may be built up entirely of non-volcanic materials. In the peperino of Italy we have a leucite tuff with many inclusions of non-volcanic rocks, such as limestone, sometimes in large blocks, at others in the form of fine dust. In the cave sandstone of the Drakensberg we have a tuff which is composed entirely of non-volcanic dust, grains of quartz, microcline, plagioclase, tourmaline, epidote, etc., with only an occasional ash-bed. I suspected its origin, when first studying it in Matatiele, from the fact that it was found thickest near the volcanic vents. Its nature, also, showed clearly that it was not an ordinary sediment; for there are beds of this rock 800 feet thick without a trace of stratification. Sometimes there is stratification; either a plane passes slantingly through the mass from top to bottom, or it is curved and twisted as if the whole material had been stirred about in a gigantic pot. The structure of the rock was such that I finally decided that it must have been ejected as a liquid mud exactly like the Italian peperino, and that the constituent grains had been blown from the substratum of granite and Archæan schists by explosions. Von Knebel has described similar tuffs composed of disrupted granite from the Ries in Germany.[1]

In 1845 Ehrenberg described a remarkable tuff from the Island of Ascension containing infusoria, which he called a pyrobiolith.[2] Prestwich surmised that these "diatoms" had lived in subterranean caverns which the explosion had traversed,[3] but the *Challenger Reports* state that the organic remains are the siliceous particles of grasses. It seems probable that this tuff was erupted as a boiling liquid mud, which, traversing a plain covered with grass, tore off by rolling action and incorporated grass fragments in the

[1] *Zeitschrift der Deutschen Geologischen Gesellschaft*, Vol. LV (1903), pp. 236–95.

[2] *Berichte der Königlichen Akademie der Wissenschaften* (Berlin, 1845), p. 140.

[3] *Proceedings of the Royal Society*, 1886, No. 246, p. 156.

substance of the mud. In view of the presence of granite blocks in the lavas, it is quite possible that some of the tuffs on these volcanic islands will turn out to be of the same nature as the granitic tuffs such as are found in the Drakensberg and the Ries in Germany.

In the Atlantic islands that do not stand on the central ridge continental types of rocks are also found, as, for instance, in the Canary Islands, where gneiss occurs; in the island of Mayo, in the Cape Verde group, Doelter found compact limestones and crystalline schists—traces, he maintains, of an ancient continent.[1]

On the whole, therefore, the evidence of a land connection between Africa and South America, afforded by the islands in mid-ocean, is suggestive, but far too little investigated to be worth much at the present time. The oceanic islands are not favorably situated for lengthened research; yet a very serious lacuna will exist in our knowledge of the geology of the earth as a whole, if they are not systematically studied. The surprising results of Woolnough in the Pacific makes one expect similar results from the Atlantic islands; and then there are the islands in the Indian Ocean, about which we know very little indeed, and the Aleutian Islands in the north Pacific, which are similarly unexplored. I urge, therefore, that these oceanic islands can and do afford evidence of the sub-oceanic crust, and if we are to understand the relation of our present continents to the waters that encompass them, we must not rely solely on the facts as presented to us in the most convenient places, round our homes, but we must put off from our shores and seek knowledge in isolated rock-masses of the ocean.

In the second line of inquiry we can consider the evidence from the American or the African side where the land bridge is supposed to have emerged.

In South Africa in Silurian times we have a remarkable band of sandstone 5,000 feet thick, coarsely false-bedded throughout, stretching from the west coast at a point about midway between the mouth of the Orange River and Cape Town, to Port Elizabeth, and then coming in again at St. John's River, quite similar in constitution, and passing eastward to Natal. This was succeeded by deeper water deposits containing characteristic Ameri-

[1] *Verhandlungen der K.-K. Geologischen Reichsanstalt* (Wien, 1881), p. 16.

can forms of life, such as *Leptocælia flabellites, Vitulina pustulosa, Spirifer orbignyi, Ambocælia umbonata, Grammysia chemungensis, Bellerophon reissi,* and many others. Following these Bokkeveld Beds come the sandstones of the Witteberg Series (the Cauda-galli grits of North America). And after this the Dwyka conglomerate, a glacial bowlder-clay with a peculiar assortment of inclusions, all of which have been now traced to rocks *in situ* in the north of the Colony and Transvaal. The whole series is plainly indicative of the existence of a land-mass in Palæozoic times whose shores ran through the south of the Transvaal and the north of the Cape Colony. The conglomerates in the Table Mountain sandstone in the west show that the land was near at hand there. But after Silurian times there is no evidence in South Africa that the sediments were derived from the west; they seem all to have been derived, as far as the Cape Colony is concerned, from the north.

Quite otherwise is it in South America. Katzer finds there the most complete evidence for the existence of a land-mass on the east, whence the sediments that now go to form the mainland were derived,[1] and this continent existed up to Tertiary times. The long residence of this author at Para and his wide acquaintance with the literature of South America make his conclusions peculiarly valuable. In Devonian times the existence of the *Leptocælia flabellites* fauna in South Africa, the Falkland Islands, South and North America, has led many to suppose that the European seas were separated from the waters under which the Devonian sediments were being laid down containing this fauna, by a land bridge; Katzer has called it the Atlantico-Ethiopic Continent,[2] and I, Flabellite Land, after the characteristic fossil *Leptocælia flabellites*. From a review of the Jurassic faunas Neumayr came to the same conclusion as others have come to, from considering the extension of the Devonian faunas.[3]

Finally, if the bridge lasted as late as the Tertiary period, we must expect the distribution of land animals to have been affected

[1] *Grundzüge der Geologie des unteren Amazonasgebietes* (Leipzig, 1903), p. 239.

[2] *Bol. d. Mus. Paraense,* Vol. II (1895), plate, p. 237.

[3] *Denkschriften der K.-K. Akademie der Wissenschaften,* Wien, Vol. II (1885), p. 132.

by it, and such we find to be actually the case. The late Dr. Blanford, in his anniversary address to the Geological Society of London in 1890, went thoroughly into the question in regard to the fresh-water fishes and batrachians. In a subsequent letter I received from him he wrote:

> I have long been aware of the extraordinary connection between the faunas of Africa and South America, only a very few examples of which were known when I wrote about ancient continental connections in 1890. For instance, the fresh-water crustaceans have been examined by Dr. Ortman,[1] spiders by Pocock,[2] and several other groups by Dr. Scharff.[3] I have heard of an amphisbæna (belonging to the family of lizards, chiefly confined to Africa and South America) turning up at one of the South Atlantic islands (Trinidad, off the Brazilian coast I think), but I cannot now find the reference.

Boulenger, in his presidential address to the zoölogical section of the British Association at the South African meeting, stated that, although it was possible to get the present distribution of fresh-water fishes without a land-bridge between Africa and South America, yet a connection would immensely simplify the explanation of their dispersal.

There are many naturalists who do not think that the evidence from living forms of life is sufficient to bring into existence in past ages such a tremendous rearrangement of the land-surfaces, but if the geologists from their side can adduce satisfactory reasons for such a submerged land connection, most of their opposition would vanish, for the connection does help to explain matters very considerably. If geologists rely on elaborate arguments to prove their contention, zoölogists are not likely to take the trouble to examine them; and this brings me back to my former statement, that even a little evidence from oceanic islands is of very great weight. A block of slate containing *Leptocælia flabellites*, found in Tristan d'Acunha or similar Atlantic islands, would prove more by itself than any attempt to reconstruct the direction of sedimentation in past ages, no matter how sound the arguments were. I have shown that such a find is by no means impossible, and I have endeavored to make clear what important issues hang on the proper investigation of oceanic islands.

[1] *Proceedings of the American Philosophical Society*, Vol. XLI (1902), pp. 267–400.
[2] *Proceedings of the Geological Society*, 1903, Part I, p. 340.
[3] *Proceedings of the Royal Irish Academy*, Vol. XXIV.

SOLIFLUCTION, A COMPONENT OF SUBAËRIAL DENUDATION

J. G. ANDERSSON
Upsala University, Sweden

According to the theory of river development, as it has been worked out in its full modern form by a number of eminent American morphologists, the occurrence of narrow *v*-shaped valleys in a region indicates that the region in question has passed only the very first stages of the cycle of erosion. This type of valleys, considered by older European geologists as the most important feature of river-action, is, according to the modern American school, only an immature stage in the development of river valleys.

In the course of time the blocks of land left between the principal valleys will be dissected by secondary streamlets, the valleys will be broadened, and their slopes will get more and more gentle. At last, if the subaërial denudation has time enough to fulfil its work under unaltered conditions, the hills are wholly consumed, the region is base-leveled, and the land once deeply dissected is turned into a slightly undulating plain with broad and shallow, faintly insected river valleys. Not till then has the process reached the final stage of its cycle, the "peneplain."

This theory of subaërial denudation is based upon the premise that river-erosion works all over the *areas*, and not only *linearly*, as was supposed by an older school of geologists. This assumption looks at first somewhat startling. Evidently the main stream and the principal tributaries of a river form only a branching system of erosive *lines*. Only when the innumerable rivulets and feeders, all the transient small waters washing hillsides and slopes at rainfalls and snow-meltings, are taken into consideration, does the erosive system present a network so close that it can be said to cover all the area.

In its finest embranchments, in the region of the primal feeders,

the erosive system is highly supported in its work by the weathering of the rock and by *a slow movement of the waste-sheet down the slopes*

The latter process, generally little estimated, has been clearly sketched by the master of the American "base-leveling" school, W. M. Davis:

> The movement of land-waste is generally so slow that it is not noticed. But when one has learned that many land forms result from this removal of more or less waste, the reality and the importance of the movement are better understood. It is then possible to picture in the imagination a slow wasting and creeping of the waste down the land slopes; not bodily or hastily, but grain by grain, inch by inch; yet so patiently that in the course of ages even mountains may be laid low. . . . . Every change of condition between cold and warm, dry and wet, melted and frozen, that causes a gain or a loss of volume in the rock-waste aids its slow movement down-hill. With countless minute changes every particle is led, slowly but surely, from higher to lower ground.[1]

It seems to me that it is in the removal of the waste, by which the undecayed rock is again exposed to the attack of the weather and the débris is carried to the primal streamlets, that this process, in its more or less rich development, chiefly determines the effectiveness of river-action in peneplaining. Professor Davis supposes that the removal of the waste may continue also underneath a cover of vegetation, and he points out that "the growth and decay of plant roots aid the downward creeping of the waste." But experience has taught us that in regions covered by a rich vegetation the removal of the débris must be very slow, as the unaltered rock is, in most cases, hidden by a deep covering of decayed material. In those lands where the climatic conditions are unfavorable for the removal of the waste the material carried away by river transport must be comparatively scarce and the subaërial denudation only very slow in its advance toward its final end, the peneplain.

But, on the contrary, in regions where the vegetation, because of the hostility of the climate, is all too scarce to fix the detritus, but when the precipitation is still abundant enough to cause effective action by running water, a quick removal of the waste and a plenteous feeding of the streamlets with detritus highly accelerate the subaërial denudation.

During the last few years I have had opportunity of studying,

[1] Davis, *Physical Geography*, pp. 263, 267.

under high northern and southern latitudes, regions where the removal of the waste is now going on under peculiar conditions, and in another case was working during a bygone climatic depres-

FIG. 1.—Bear Island. Sea cliff, 400 meters in height.

sion in a most effective manner almost all over the area of the islands under consideration.

I have thought it possibly useful to publish a short preliminary review of my observations, as they may add to the understanding of an important component of subaërial denudation. The phenomenon I am going to describe is by no means new to science; on the contrary, it has been noticed and clearly described by many skilled observers from different parts of the world, where the con-

ditions are favorable for its development. But it seems to me that there has been a tendency to depreciate its importance as a link in the series of denudative agents, and to look at it as only a curiosity of mere local nature. No one, as far as I know, has collected the scattered material, as I will try to do in the following pages, and probably few have had an opportunity like mine to study the phenomenon in its fullest development.

SOLIFLUCTION IN BEAR ISLAND

This islet situated in 74½° N. L., in the Atlantic part of the Arctic Ocean, is a small remainder of a once larger stretch of land. Sea cliffs, in some places rising to the height of 400 meters and fringing the island almost all around, tell us of the destructive action of the abrasion. The northern and larger part of the island forms a lowland plateau rising very slowly from the recent coastal outline to the interior and cut out through slightly dislocated Devonian and Carboniferous beds. Several reasons, among others the occurrence of old, somewhat obliterated coastal cliffs at the inner margin of this plateau, incline me to consider it as worked out by marine abrasion.

The southern part of the island is mountainous, with tops rising to 460–539 meters. In this region the ground is composed of a great variety of sedimentary rocks from Silurian to Triassic age, and the older strata are cut up by vertical dislocations into a few parallel blocks. In some cases the denudation has laid bare parts of the precipitous surfaces of the faults, but as a rule the land-sculpturing agents show a marked tendency to smooth the tilted blocks to rounded hills and broad river valleys with gentle slopes. Thus the land forms of the interior of the island are in a striking contrast to the perpendicular cliffs on the sea side.

On the hill-slopes and valley sides of Bear Island there are almost everywhere clear indications of a moving of the waste from higher to lower ground. Many of the small hills show a very marked streakiness of surface, which is due to the peculiar arrangement of the detritus; sometimes the flowing soil forms real streams which have much likeness to a glacier in miniature, and often in the depressions between the hills there are numerous small circular or semi-

circular walls composed of rock fragments and including a patch of muddy material, often hardened through desiccation. Evidently all these phenomena only represent different facies of the displacement of the waste.

It is not very difficult to find out the mode of formation of the "mud-glaciers" mentioned above. When in summer time the melting of the snow has reached an advanced stage, often the bot-

FIG. 2.—Scenery from the southern part of Bear Island, showing the contrast between the rounded land-forms caused by subaërial denudation and the perpendicular coastal cliffs caused by marine abrasion, dissecting the island.

tom of the valleys are free from snow, while big masses still rest in sheltered places on the valley sides. Every warm and sunny day new quantities of water trickle from these melting drifts into the rock-waste at their lower edge. As the masses of detritus are composed not only of coarser rock fragments such as blocks, slabs, and gravel, but also of finer particles filling the interspaces between the coarser material, they are able to absorb considerable quantities of water. When once saturated, they form a semifluid substance that starts moving slowly down-hill. This process, the slow flowing from higher to lower ground of masses of waste saturated with water (this may come from snow-melting or rain), I

propose to name *solifluction* (derived from *solum*, "soil," and *fluere*, "to flow").

As the snowdrifts of Bear Island diminish in the course of the summer, new ground is exposed, its waste is thawed, and then, saturated with water, it follows the slow downward movement. The flowing detritus does not generally move as a "sheet-flood" with a broad front, but more often flows in some slight depression of the slope, taking the form of a narrow tongue, offering a most striking parallel to a glacier. The névé region is represented by the area of water-saturated detritus at the lower edge of the melting snow-drift, and the flowing tongue of mud is the glacier proper that moves down the valley. The terminal moraine even is often to be seen in the shape of slabs and pieces of rock that the mud-stream has pushed together in front of its lower end.

These mud-streams do not consist of finer particles only, but also of coarse material, gravel and blocks, frequently intermixed with, and also carried on the top of the muddy substance.

Small mud-glaciers of the type just described are very common in Bear Island, and sometimes they reach noticeable dimensions. On the slope of Oswald Hill I measured such a tongue of detritus that had a breadth of 35 meters and a depth (thickness) of at least 2.1 meters. In this case "the terminal moraine" was represented by a zone of sandstone plates, pushed together so that they were all standing edgewise beautifully concentric to the rounded front of the detritus tongue, and this piled-up zone had the rather startling width of 17 meters! This example may give some idea of the considerable quantity of detritus that can be removed in a single stream, as well as of the energy which such a mud-glacier can develop before its movement is arrested.

My companion in the voyage to Bear Island, Dr. G. Swenander, during his botanical researches made an observation that was highly illustrative for a proper understanding of the extent and importance of the solifluction.

Bear Island looks very barren also when compared with more northern Arctic islands, and its sterility is proved not only by the small number of species of higher plants, but also by the complete barrenness of large areas

Swenander gave an explanation of this scantiness of the flora: All the phanerogamic plants of Bear Island—with the exception of a single species—are perennial, and these forms cannot endure upon the flowing soil, where they are easily drowned in the moving mud. The sterility of the areas of solifluction is quite a striking feature of the island. On many slopes small hills of the solid rock crop out of the covering of moving waste, and, though the soil is very scant in the small fissures and crevices of the rock, here the plants grow more willingly than upon the perfidious flowing ground. Thus these small rocky hills form cheerful verdant patches scattered over the barren slopes. In the rare cases when Swenander found single plants growing upon the moving waste, he could demonstrate a remarkable adaptation to this mode of life. The root system of these specimens was exceptionally developed in order to keep the plant afloat on the moving medium. These roots were stretched out in the direction of the movement of the soil, and in some cases where the slope was very steep it was noticed that the proximal part of the root system, carried by the more rapid flowing of the superficial layer of the mud-stream, had reached a *lower* level than the distal branches, which, joining the slower movement of deeper parts of the stream, were left behind in the displacement down-hill. These facts, which I owe to my friend Dr. Swenander, illustrate better than anything else the mode of progress and the importance of solifluction in Bear Island. Evidently, then, this process is a chief agent of the denudation. Every summer large masses of detritus in this way flow down-hill into the bottom of the valleys, where the streamlets undertake the work of transport. It is characteristic for this hitherto undervalued component of subaërial denudation, which I have named "solifluction," that—in contrast to the wind and the running water—it does not lift its material, but like the glacier-ice—with which it has been already compared—it removes blocks and gravel almost as well as the fine mud.

THE STONE-RIVERS OF THE FALKLAND ISLANDS

This island group, situated in 52° S. L. in the South Atlantic, consists of two large and a great number of small islands. The East Falklands, and to some extent also the western large island,

present an undulating land surface built up by slightly folded Devonian beds and evidently subjected for a long time to subaërial denudation. With the exception of some resistant quartzite ridges, they, and especially the eastern island, are far advanced toward the peneplain. The land is woodless over large areas, and occupied by peat-bogs, the drier places forming grass steppes and the very driest heaths covered by *Eupetrum rubrum.*

This landscape, as bewildering through the monotony of its outlines as deterring through its ugliness, boasts a natural phenomenon that may be unparalleled in the world. The "stone-rivers," which form a beloved object of the fancy of the population, were lucidly described by Charles Darwin, though he could not find a satisfactory explanation; but a later visitor, Sir Wyville Thomson, got very near to a proper understanding of the thing. In order to demonstrate the process in question, I quote the condensed description given by the eminent naturalist of the "Challenger:"

> In the East Island most of the valleys are occupied by pale gray glistening masses, from a few hundred yards to a mile or two in width, which look at a distance much like glaciers descending apparently from the adjacent ridges, and gradually increasing in volume, fed by tributary streams, until they reach the sea. Examined a little more closely, these are found to be vast accumulations of blocks of quartzite, irregular in form, but having a tendency to a rude diamond shape, from two to eight or ten or twenty feet long and perhaps half as much in width, and of a thickness corresponding with that of the quartzite bands in the ridges above. The blocks are angular like the fragments in a breccia, and they rest irregularly one upon the other, supported in all positions by the angles and edges of those beneath.[1]
>
> There can be no doubt that the blocks of quartzite in the valleys are derived from the bands of quartzite in the ridges above, for they correspond with them in every respect; the difficulty is to account for their flowing down the valley, for the slope from the ridge to the valley is often not more than six to eight degrees, and the slope of the valley itself only two or three, in either case much too low to cause blocks of that form either to slide or to roll down.
>
> The process appears to be this: The beds of quartzite are of very different hardness; some are soft, passing into a crumbling sandstone; while others are so hard as to yield but little to ordinary weathering. The softer bands are worn away in process of time, and the compact quartzites are left as long projecting ridges along the crests and flanks of the hill ranges. When the process of the disintegration of the softer beds has gone on for some time, the support

[1] Thomson, *The Atlantic*, p. 245.

of their adjacent beds is taken away from the denuded quartzites, and they give way in the direction of the joints, and the fragments fall over upon the gentle slopes of the hillside. The vegetation soon covers the fallen fragments, and usually near the sloping outcrops of the hard quartz, a slight inequality only in the surface of the turf indicates that the loose blocks are imbedded beneath it. Once imbedded in the vegetable soil, a number of causes tend to make the whole soil-cap, heavy blocks included, creep down even the least slope. I will only mention one or two of these. There is constant expansion and contraction of the spongy vegetable mass going on, as it is saturated with water or comparatively dry, and while with the expansion the blocks slip infinitesimally down, the subsequent contraction cannot pull them up against their weight; the rain-water trickling down the slope is removing every movable particle from before them; the vegetable matter on which they are immediately resting is undergoing a perpetual process of interstitial decay and removal. In this way the blocks are gradually borne down the slope in the soil-cap and piled in the valley below. The only other question is how the soil is afterwards removed and the blocks left bare. This, I have no doubt, is effected by the stream in the valley altering its course from time to time, and washing away the soil from beneath.[1]

This explanation given by Sir Wyville Thomson, referring the formation of the stone-rivers to the slow removal of the waste down the slopes, must be willingly accepted by everyone who has studied the "stone-runs" in nature. The only objection, and that a very essential one, is against the idea of the phenomenon as a product of present conditions and of the process as still working with full effectiveness underneath the vegetation that now partly covers the stone-rivers. It ought to be noticed that long before I visited the Falkland Islands and studied in detail one of the stone-rivers, James Geikie, knowing these tracts only from the descriptions of Darwin and Thompson, had already expressed the opinion that the stone-runs were comparable to the rubble-drifts of England, or otherwise that they were formed in a bygone period, characterized by a climate more severe than the present.[2]

When I came to the Falkland Islands in 1902, I did not know of the ingenious comparisons made by James Geikie, but with my earlier experience from Bear Island it was easy to go straight to a full understanding of the thing.

Solifluction, in its quite typical form, is still at work in the Falkland Islands, but only on a small scale in favorable localities where

[1] *Ibid.*, pp. 246–48.

[2] Geikie, *The Great Ice Age*, 3d ed. (London, 1874), pp. 722, 723.

the hillsides are steep, the vegetation scarce, and the trickling water saturates the soil.

On the slope of Stephens Peak, a conical sandstone hill on the south coast of West Falkland, I found a recent mud-stream extending almost from the top of the mountain to its base, with a breadth of 32 meters where it was widest. The fall of the stream was 11–19°. Its material was a kind of stony clay charged with big blocks, the whole having much resemblance to some types of the glacial till. Also on the surface of the stream there lay numerous blocks, the largest having a diameter of 1.5 meters. I removed several of these big blocks to examine their bedding, and I always found them to rest upon the stony mud, never upon a basement of other blocks or solid rock.

In other parts of the same slope I found ancient mud-streams which were bordered by vegetation and evidently fixed at the present time. In some places the fine material was washed away by surface water, only to leave a residuum of sandstone blocks, a copy in miniature of the large stone-runs. Between the latter and the recent mud-streams of Bear Island my observations on the slopes of Stephens Peak gave all the transitional stages.

But although the solifluction is still working in exceptionally favorable places in the Falkland Islands, it seems to me quite evident that the large stone-runs, which are covered with vegetation in all places where the fine material is not washed away, were formed in an earlier period, when the solifluction was working in this region upon a much larger scale than today. Apparently several changes in the level of the land and in the condition of the climate have passed over these wonderful, timeworn giants.

I have studied in detail, and surveyed in the scale of 1:20,000, the big stone-river (possibly the largest in the islands) south from Port Louis, which was originally described by Darwin. In a coming paper I will publish this material *in extenso*, but for the present purpose the following brief remarks may be sufficient.

The open areas and strips consisting only of a chaotic accumulation of large blocks of quartzite evidently have been formed by a secondary washing away of the finer material that once filled all the interspaces between the big blocks or carried parts of them

on its surface. As will be demonstrated by my map, the contours of these vegetationless block-fields, with all their embranchments, give the rude outlines of a small river system, and, as has been mentioned already by Darwin and Thompson, in many places the purling of running water is heard far down below under the blocks, indicating the recent course of a stream in the depth of the stone-river.

But the real extent of the ancient *flowing slopes* is much larger than that indicated by the open vegetationless block-fields. In all places where running water has not washed away the fine material the old detritus flows remain in their original composition and offer a soil which is able to carry a covering of vegetation. Where there is a small cut of any kind in such an unaltered part of the slope, it is easy to recognize that the mass underneath the mantle of vegetation is the same as in the waste-streams on Stephens Peak, large blocks imbedded in fine rock detritus.

The large old stone-runs of the Falkland Islands evidently were formed in a period of the past with a climate more severe than the present, with heavy snowfalls in winter, but also with summers characterized by active snow-melting, causing an intensive solifluction which was ever victorious in the fight with the then poor and scattered vegetation. I fancy that in these days the state of the Falkland Islands was very much like that which I have actually studied on the Bear Island of today.

It is very inviting to connect this birthtime of the Falkland stone-rivers with the great climatic depression of a bygone time that has been demonstrated in the adjacent southern lands.

In Tierra del Fuego and the south part of Patagonia Darwin, Agassiz, and O. Nordenskjöld have studied the moraines of an old land-ice extending to the Atlantic Ocean, in South Georgia I have traced a complete glaciation of the island, and in the Antarctic region, in Graham Land, Arctowski, Nordenskjöld, and myself have found full evidence of an earlier, much larger extension of glaciers and land-ice.

To the west, east, and south the Falkland Islands are surrounded by lands deeply furrowed by an old ice age. In our islands, on the contrary, there are no traces of an old ice-sheet, no grooving

THE UNIVERSITY LIBRARY OF GEORGIA

of the rock-surface, no moraines, and some very characteristic relief forms are directly incompatible with the hypothesis of an earlier ice-action upon the islands.

But, on the other hand, it seems impossible that the great wave of cold, which has set its mark so severely upon the surrounding lands, should have left no traces on the Falkland Islands. Nothing is then more natural than the presumption that the birth of the stone-rivers is a facies of the ice age of the southern lands. In the Falkland Islands the climatic depression was not severe enough to cause a glaciation, but only an intensive frost-weathering and flowing slopes, quite as today in Bear Island we have no glaciers, but only a marked solifluction.

The stone-rivers certainly are the most striking feature of the inland scenery in the Falkland Islands. Never did I feel them more imposing than in a voyage along the southern coast of East Falkland. Then, behind the lowland forming the south part of the island, I saw in the distance the Wickham Heights, the principal watershed, in its full extent. Every transverse valley of the low mountain range was filled by the gray mass of a stone-river extending to or upon the lowland at the mountain's foot. The resemblance to a region crowded by valley glaciers was really amazing.

The unsurpassed grandeur of the Falkland stone-rivers was sufficient to provoke the idea that in this island group the solifluction has been at work on a larger scale than anywhere else on the present earth surface. But I think that this effect of the solifluction, that we meet with in the stone-runs, is rather exceptional, depending upon the petrological character of the rock yielding the material to them.

As already cited, Sir Wyville Thomson has clearly described how the mountain ridges, from which the stone-rivers flow, consist of hard, thick quartzite-bluffs, with intercalations of more soft material. The last-mentioned softer bands are successfully attacked by the weathering and turned into a muddy mass forming the matrix of mud-streams. The quartzite bluffs, thus deprived of their footing, break down in big blocks, and these are carried down-hill by the mud-streams. In the bottom of the valley the fine material is removed by running water, and there is left a very

abundant residuum of huge, hard quartzite blocks, almost unattackable by weathering. Such a result of the combination of solifluction and river-action will be reached only with rocks com posed of an alternation of soft and extremely unattackable material. In other cases also the big blocks will gradually succumb to the weathering, the river will be able to clear its course. and new mud-streams will follow those already washed away by the running water.

Also in this respect a comparison with the conditions of Bear Island is highly instructive. In the southern, mountainous part of the island, where I have studied the solifluction in its most varied development, and where the ground is for the larger part composed of rocks (slates, limestone, dolomite), which are through all its mass almost uniformly attackable by weathering, I have found, in the course of the small rivers, no accumulations of big, irregular blocks like those of the stone-rivers. But as soon as one enters the areas of the Ursa sandstone—a rock in parts much like the sandstone of the Falkland Islands, and consisting of alternating hard quartzites and soft intercalations—the aspect of the ground is quite altered. The vast Ursa sandstone area on the flat land in the north of the island is all densely covered over with huge, edged blocks, the whole forming a regular Gehenna for the wanderer—quite as the stone-rivers.

I feel sure that these immense block-fields of Bear Island are formed in quite the same manner as the Falkland stone-runs: by weathering of the rock; by solifluction (though this is very slow and hardly perceptible in the great plain of Bear Island); finally also by the action of running water. The only differences between the two occurrences are differences of topography and of age: in Bear Island a great plain forming a *stone-field*, in the Falkland Islands valleys filled at the bottom by *stone-rivers*—the former a recent, the latter a fossil occurrence.

According to the relation given above, the Falkland Islands are characterized not so much by the extreme intensity of the solifluction in a past time as by an exceptional abundance of the residuum left by the running water that has sifted the material of the old mud-streams. Under other petrological conditions the result

of the combination of solifluction and river-action will be, not the formation of stone-rivers, but—if the time of their action has been long enough—the leveling of the land to peneplain.

REGIONAL EXTENSION OF THE SOLIFLUCTION

From Bear Island in the arctic and from the Falkland Islands in the subantarctic regions I have described in the previous pages two occurrences of solifluction—one recent, the other fossil—where in both cases the phenomenon is developed in rather exceptional dimensions. But, if often only in a moderate scale, this mode of waste transport works in many parts of the world. In the geological, geographical, and botanical literature there are to be found many notes on mud-streams and flowing slopes, illustrating the process here in question. In the following pages I have collected, partly with the assistance of helpful friends, some descriptions of of soil-flowing, but the list of them is given without any pretentions to completeness. Surely many a valuable note on processes of this kind has escaped me, and I hope that colleagues in different lands, after having read this article, will kindly call my attention to observations still unknown to me.

South Georgia.—This subantarctic island is a ridge of folded land, deeply indented by transverse fiords between which the mountains rise steeply to 1,000–2,000 meters. Small glacier caps of varied type occupy a large part of the mountains, and in many of the valleys splendid glacier streams extend into the fiords. But the narrow lowland strips and much of the mountain slopes were free from ice-covering, and here frost-weathering, solifluction, and running water are the chief agents of destruction. Slowly moving slopes and small mud-streams were frequently seen, and the forms of the detrital masses offered many a striking parallel to my earlier experiences on Bear Island.

Graham Land.—The ice-covering of the antarctic lands is all too complete to leave any place for solifluction on a large scale; but on the very limited areas where the land was exposed we could trace almost everywhere this mode of transport working in the summer. On the plateau above the winter station on Snow Hill, Nordenskjöld kindly pointed out to me a locality where the land

surface showed the same streakiness that I had seen before in Bear Island, beautifully developed, and which was evidently due to displacements of the soil.

North America.—I have had no time for looking into the immense American literature for notes indicating observations on solifluction, and shall be most thankful for any information on this subject relative to that continent where the land forms are so splendidly developed and so admirably surveyed.

FIG. 3.—Fox Bay, West Falkland. Scenery showing the vast plains and the low, rounded mountains.

The only observation from the United States that I am able to mention here is cited by James Geikie in *The Great Ice Age*, and is taken from Hayden, who has given a very illustrative description of solifluction in some valleys in the Rocky Mountains. These valleys are

> covered thickly with earth, filled with more or less worn rocks of every size, from that of a pea to several feet in diameter. The snow melting upon the crests of the mountains saturates these superficial earths with water, and they slowly move down the gulch much like a glacier.[1]

[1] *Geological and Geographical Survey of Colorado*, 1873, p. 46.

A note on "flowing soils" is also cited by James Geikie[1] from the arctic part of the American continent. The observation was made by Sir Edward Belcher on Buckingham Island in 77° N. L. He ascended a hill 200 feet above the sea to make observations, and found the soil well frozen and firm and covered with a slight crust of snow. But as the power of the sun increased toward noon, the snow disappeared.

> As noon passed the soil in all the hollows or small watercourses became semifluid, and very uncomfortable to walk on or sink into. At the edge of the southern bank the mud could be seen actually flowing, reminding one more of an asphalt bank in a tropical region than our position in 77° 10′ N. The entire slope, in consequence of the thaw, had become a fluid moving chute of débris for at least one foot in depth.[2]

Spitzbergen.—During the arctic expedition of 1898, under the command of Professor A. G. Nathorst, when I made my first acquaintance with the solifluction in Bear Island, I also had opportunity to see some phenomena of this kind in Spitzbergen, where they were studied somewhat more in detail in the neighborhood of Hecla Cove, in Treusenberg Bay by my companions G. Andersson, H. Hesselman, and A. Hamberg. The following year, 1899, Dr. Th. Wulff made some observations on the same phenomenon in the first-named place and in Green Harbor in the Ice Fiord.[3]

Recently Professor DeGeer has given a brief account of his researches on moving slopes made during several expeditions to Spitzbergen, partly long before the observations mentioned above.[4] DeGeer has noticed the phenomenon in several localities in the Ice Fiord region, as at the Wahlenberg glacier, at Temple Bay, where the cover of vegetation had got dispersed by a mass of moving soil, and at Cape Thordsen. At the last-mentioned place a small railroad was built many years ago (1872) for mining purposes. Ten years later the railroad could still be used, but in 1896 De Geer found it to be greatly distorted by the effect of the moving soil.

De Geer points out that the waste-sheet generally moves over a bedding of frozen soil, and that also regelation may act in the displacement of the moving masses.

[1] *Op. cit.*, pp. 387, 388.

[2] *The Last of the Arctic Voyages*, Vol. I, p. 306.

[3] Th. Wulff, *Botanische Beobachtungen aus Spitzbergen* (Lund, 1902), pp. 85, 86.

[4] *Geologiska Föreningen i Stockholm Förhandlingar*, 1904, pp. 465–66.

Scandinavia.—From the mountainous region of Valders in Norway H. Reusch has given a very interesting description of solifluction.[1] To judge from his sketches and verbal testimony, the phenomenon here is very similar to what I have studied in Bear Island, though not so largely developed.

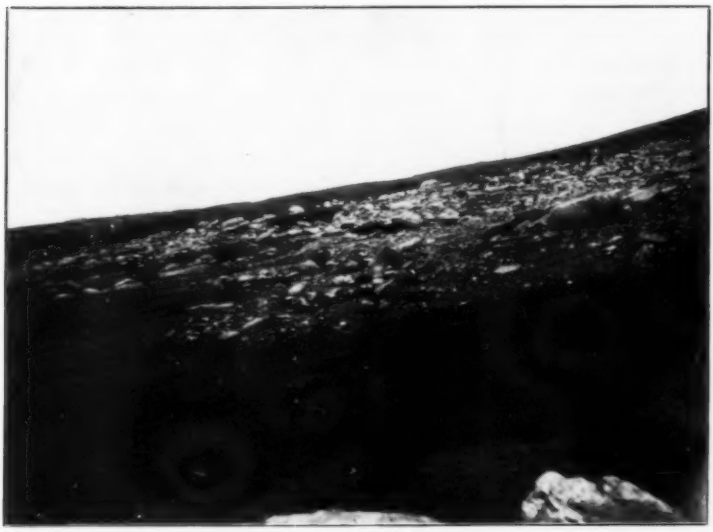


FIG. 4.—Recent mud-stream charged with big blocks. Stephens Peak, West Falkland.

From Sweden a considerable number of notes on solifluction have been published quite recently, after my lectures on the flowing slopes of arctic and sub-antarctic islands had directed the attention of our geologists to the problem.

R. Sernander has given some very important observations from Häijedalen, commenced in 1895 and largely supplemented in the summer of 1904.[2] In the places studied by him, and as a rule in all parts of the mountain regions of Sweden where the process has been noticed, it has given origin only to small narrow terraces, not to far extended mud-streams—a difference possibly indicating

[1] *Norges Geologiske Undersögelse, Aarbog*, 1900, pp. 75, 76.
[2] *Geol. Fören. i Stockholm Förh.*, 1905, pp. 42 ff.

that the solifluction here works with less intensity than in the tracts studied by me.

Detritus terraces of the type mentioned have been noted by De Geer on the Ovik Mountains in Jämtland, and by Svenonius at Sitasjaure and Vassijaure in Swedish Lappland.[1]

All these observations are made in the high mountain regions, but Professor Högbom has, in a very interesting paper, called attention to the fact that under favorable conditions solifluction can work on a rather large scale also in the woody lowlands of Norrland, and in some rare cases also in more southern parts of Scandinavia. Högbom describes from Lule River how forest trees growing on slowly moving ground are deformed, and he clearly demonstrated that in the fine fluviatile sediments, filling the lower parts of the large river valleys in Norrland, soil-flowing in some places is a very important transporting agent.[2]

Tibet.—In the vast Tibetan highlands Dr. S. Hedin during his last expedition underwent most trying experiences of solifluction. For days and weeks his caravan struggled through a terrible quagmire of water-saturated detritus. Many a time the animals were brought out of the treacherous soil only with the utmost difficulty, and once a camel got lost in such a morass. "The poor beast was literally swallowed up in the mud, and all attempts to get him out failed."[3]

The descriptions by Hedin clearly show that the saturated soil actually moves down-hill, and that the solifluction in those far-extended highlands works on a very large scale, lowering the mountains and filling the valleys:

> I could not help thinking that the whole bunch of hills would, like a viscous fluid or thick porridge, gradually flatten themselves out to a uniform level. This conformation was caused by the incessant precipitation searching into the ground and making it like a sponge; for only a very small quantity trickled into the superficial brooks and rivulets, and so flowed away. The absence of vegetation with its interlacing roots also contributed to the same result. In two or three places *the shales stuck up edgewise* and cut the camel's feet.[4]

[1] *Geol. Fören. i Stockholm Förh.*, 1904, p. 466.

[2] *Ibid.*, 1905, pp. 19–36.

[3] S. Hedin, *Central Asia and Tibet*, Vol. II, p. 288.

[4] *Ibid.*, Vol. I, p. 519. Italics are mine.

The slope consisted of a gigantic sheet of mire, of the consistency of porridge, and to judge from the cracks which ran across it and all round it, the entire mass was slipping slowly, though imperceptibly, down the mountain-side.[1]

All the notes collected in the preceding pages deal with regions of *recent* solifluction. But of *fossil* occurrences of the same kind indications are to be found in the literature.

In the southmost part of England, outside the area of maximum glaciation, there is widely distributed a peculiar kind of deposit known by the name of "rubble drift," "head," etc., and consisting "of a more or less coarse agglomeration of angular débris and large blocks set in an earthy matrix."[2] This kind of soil is described from Cornwall and Devon, from the South Downs and from Guernsey, one of the Channel islands. According to the opinion of James Geikie and other English geologists, these beds were formed principally by solifluction as an extra-marginal facies of drift at the time of the maximum glaciation.

A deposit of the same kind is the massive breccia of Gibraltar, described by Sir A. C. Ramsay and James Geikie. It is a rude accumulation of angular fragments of limestone, of all shapes and sizes, imbedded in a calcareous grit and earth. As to its formation Geikie writes: "When the snow melted in summer, the rubbish, becoming saturated, would move forward *en masse*, like the so-called earth-glaciers of the Rocky Mountains, as described by Hayden."[3]

It is remarkable that there are two different horizons of limestone breccias at Gibraltar, indicating two separate epochs of severe climate.

After hearing my description of the Falkland stone-rivers and the explanation of them as a facies of the ice age, Professor Högbom called my attention to occurrences of the same kind in the Ural Mountains.

They are mentioned by Tschernyschew in *Guide des excursions des VII. Congrès géologique international*, Vol. III, pp. 28, 29, when describing the quartzite mountains in the environments of the mines of Bakalsk:

[1] *Ibid.*, Vol. II, p. 286.

[2] Geikie, *The Great Ice Age*, p. 389. [3] Geikie, *op. cit.*, pp. 599, 600.

Leurs versants sont couverts d'énormes éboulis des mêmes grès et quartzites, rendant très possible l'accès du sommet. Les amoncellements de grès d'un blanc de neige et de quartzites qui descendent dans les vallées latérales, offrent un aspect très original; de loin ces trainées, de pierres ressemblent de vrais cours d'eau, tant le caractère de leurs sinuosités rappelle les véritables torrents.

One of these Ural stone-rivers is figured in Ratsel, *Die Erde*, Vol. I, p. 479, this figure showing a complete resemblance to the Falkland stone-runs, only with the exception that the Ural stone-river is bordered, not by a grass steppe, but by pine forest. According to a communication given by Högbom, the region of the Ural stone-rivers lies outside the area of earlier glaciation. Nothing is then more natural than to explain also these formations as an extra-marginal equivalent to the ice-sheet.

To this account of fossil occurrences of solifluction we must add that Sernander in the mountain region of Härjedalen has found evidence of a considerably larger extent of the flowing soil in a bygone past of the postglacial epoch.[1]

The study of the traces of solifluction in earlier times is highly attractive, and of great importance for the understanding of the climate of the past and for the explanation of the chronology of the Quarternary period in extra-glacial regions. But these are problems which lie outside the scope of this article, and which, moreover, I will treat in detail in a paper on the geographical development of the Falkland Islands.

CONCLUSIONS

From the evidence given in the preceding pages it is easy to recognize the climatic features which form the optimum of the solifluction. In the polar and subpolar regions, where the ground is not covered with ice, we find this process working with more or less intensity almost everywhere, and in the same manner, the alpine tracts of lower latitudes are favorable for the development of this phenomenon. In these regions, characterized by a "subglacial" climate with heavy deposits of winter snow melting in summer, solifluction is a chief agent of destruction. The unceasing succession, summer after summer, of mud-streams and

[1] *Geologiska Föreningens Förhandlingar*, 1905, pp. 42–84.

FIG. 5.—Part of the large stone-run south from Port Louis, West Falkland.

The light-gray mass in the bottom of the valley is the open block field, consisting only of a chaotic accumulation of big blocks. The dark narrow strips are covered by a vegetation of *Empetrum rubrum*. In these strips, as well as in the areas (dark gray on the photograph) covered by grass vegetation, fine material still fills the interspaces between the big blocks. The maintenance of unaltered strips in the largely washed block-field must be due to the original arrangement of the once slowly moving masses. Thus these strips of *Empetrum* and grass give clear indications of the direction of the movement in the old flowing slopes. From small transverse valleys in the background minute stone-runs descend into the principal valley, and here a real network of open block areas and grass patches gives to the eye in the distance a most wonderful imagination of a semi-fluid mass investing the valley. The photograph being taken in winter, the mountain hills are partly snow-covered.

moving slopes indicates that here the removal of the waste runs on at a rate that may be unsurpassed in other parts of the earth's surface—except in the deserts.

But this effective removal of the waste must be balanced on the one hand by a rapid production of new waste, and on the other, by an effective clearing out of valley bottoms by running water. The "subglacial" climate is most favorable for both these processes. In the extra-glacial regions the frost-weathering works with an intensity well known to every student of polar lands and alpine mountains, and the violent summer floods caused by the melting of the winter's snow give to the rivers of these regions an erosive power that is quite surprising.

When all these conditions are taken into consideration, the "subglacial" climate must be looked on as an optimum of destructive action. In fact, the high mountains, the large folded ranges, where all the agents mentioned work in high intensity, are found to be short-lived features in the earth's surface. In fact, one might be tempted to raise the question whether complete peneplanation is possible in regions where the action of running water is not supported by an effective removal of the waste, such as is produced by solifluction. With this premise, every peneplain found a climatic token of the same kind as the stone-rivers of the Falkland Islands and the limestone breccias of Gibraltar. Still I think that such a presumption hides a dangerous exaggeration. It is very possible that in many cases, under other climatic conditions of less erosive power, the process has had time to reach, though at a very slow rate, the end of the cycle of erosion.

But, on the other hand, it seems certain that solifluction has often been an important agent toward peneplanation. The importance of the process, because of its humbleness, has been much undervalued. But I feel sure that it is not until we get a knowledge of all the contributive agents that we can reach a full understanding of all the varied and complicated forms of land-sculpture.

LOCAL GLACIATION IN THE CATSKILL MOUNTAINS

JOHN LYON RICH
Cornell University, Ithaca, N. Y.

The Catskills, next to the Adirondacks, are the highest mountains in New York state. Several peaks rise well above 4,000 feet, while the great majority of the mountains in the central part of the area have an elevation exceeding 3,000 feet. Such an elevation naturally produces greater precipitation and a climate considerably colder than that of the surrounding country, as the following extracts from the report of the New York Weather Bureau plainly show. Five stations have been selected for comparison: Griffin's Corners, in the heart of the Catskills; Oneonta, in the foothills to the north; Albany, Binghamton, and Ithaca. Mean temperature for the years 1901–4: Griffin's Corners, 42.8°; Oneonta, 45.6°; Albany, 47.5°; Binghamton, 45.9°; Ithaca, 46.0°. Normal annual precipitation: Catskills, 40″–50″; Binghamton, 35″–40″; Albany, 35″–40″; Ithaca, 30″–35″. Winter conditions prevail there two or three weeks earlier, and persist two or three weeks longer, than in the lower parts of the state. This comparatively cool climate is an important factor, which must be taken into account in a study of the former glaciation of the region.

Comparatively little detailed work has been done on the glacial geology of the Catskills. Studies of a reconnaissance nature have, however, disclosed evidences that, in the higher mountains local glaciers persisted after the withdrawal of the continental ice-sheet. Such a condition is known to have prevailed to a greater or less extent in the Adirondacks, the White and Green Mountains, and the Katadn region of Maine. In New England, especially during the earlier study of glacial geology, considerable attention was given to the question of local mountain glaciation. A brief outline of the results of this work is given in the following section.

PREVIOUS ANNOUNCEMENT OF VALLEY GLACIERS

As early as 1856 Edward Hitchcock[1] described striæ and moraines showing a movement of ice down valleys in a direction different from

[1] *Smithsonian Contributions*, Vol. IX (1856), Art. III, pp. 135–44.

that of the principal ice-movement. Later C. H. Hitchcock,[1] Packard,[2] and Vose[3] brought forward further evidence of the same nature. Dana,[4] in view of the results of his study in the Connecticut valley, attributes most of these so-called evidences of local glaciation to the work of valley tongues from the margin of a waning ice-sheet. In a later paper[5] he suggests the probability of local glaciers having remained in the White Mountains after the ice-sheet had withdrawn. Agassiz,[6] having found a terminal moraine containing bowlders transported *northward* from their parent ledges on Mount Washington, was the first to show definitely that glaciers had moved out from the White Mountains in a direction opposite to that of the general ice-movement. C. H. Hitchcock[7] has repeatedly called attention to evidences of valley glaciation among the mountains of New England, and in his later papers[8] suggests that ice from the higher mountains, in the form of a local ice-cap, pushed outward in every direction, reaching as far north as Canada. Tarr[9] has shown that local valley glaciers existed on Mount Katadn, Maine, and suggests that further study of that region is likely to show that valley glaciers descended from several of the mountains in the vicinity. Upham[10] believes that "at the close of the glacial period, the Adirondacks, the Green and White Mountains, with probably the greater part of Maine, continued ice-covered after the glacial blockade was melted through along the Hudson, Champlain, and St.

[1] *Proceedings of the American Association for the Advancement of Science*, Vol. XIII (1859), pp. 329–35.

[2] *American Journal of Science*, Vol. XLIII (1867), p. 42; *American Naturalist*, Vol. I (1868), pp. 260–69.

[3] *American Naturalist*, Vol. II (1868), pp. 281–91.

[4] *American Journal of Science*, Series 3, Vol. II (1871), pp. 233–43.

[5] *Ibid.*, Vol. V (1874), pp. 198–211.

[6] *Proceedings of the American Association for the Advancement of Science*, Vol. X (1870), pp. 161–69.

[7] *Geology of New Hampshire*, Vol. I (1874), pp. 539–44; *ibid.*, Vol. III (1878), pp. 181–340; *Proceedings of the American Association for the Advancement of Science*, Vol. XXIV, Part II (1875), pp. 92–96; *Report of the Vermont State Geologist*, 1903–4, pp. 67–85.

[8] *Journal of Geology*, Vol. IV (1896), p. 60; *Bulletin of the Geological Society of America*, Vol. VII (1896), pp. 3, 4.

[9] *Bulletin of the Geological Society of America*, Vol. XI (1900), pp. 433–48.

[10] *American Geologist*, Vol. XXI (1898), pp. 169, 170, 380; *American Journal of Science*, Series 3, Vol. XLIX (1895), pp. 1–18; *Twenty-third Annual Report of the Geological Survey of Minnesota*, 1894.

Lawrence valleys." He has shown[1] that the moraine described by Agassiz, to which reference has already been made, is a part of a morainic belt encircling the White Mountains, and was formed at the margin of the local ice-cap which once covered them. At a later stage small local glaciers persisted in the mountain valleys.

FIG. 1.—View of a lake and its inclosing moraine built by a local glacier which descended from one of the higher ranges of the Catskills. This photograph was taken from the steep mountain valley down which the ice moved. In the foreground is a hummocky deposit representing later stands of the ice.

In the Adirondacks, Cushing[2] mentions evidence of the existence of valley glaciers either during or shortly after the retreat of the ice. Tarr, to whom I am indebted for references and helpful suggestions in the preparation of this paper, informs me that the Ausable lakes show evidences of having been formed by deposits from valley glaciers.

[1] *American Geologist*, Vol. XXXIII (1904), pp. 7–14.

[2] *Sixteenth Annual Report of the State Geologist*, New York (1896), p. 8; *New York State Museum Bulletin*, 95, 1905, p. 437.

Chamberlin[1] suggests that, in the Catskills, some of the minor moraines scattered through the mountain valleys may be due to independent local glaciers. Of this region Smock[2] writes:

> The valleys are essentially of erosive origin, obscured, however, now by glacial débris in many places. In some of them, as that of the Batavia Kill at Windham, the Stony Clove, and Woodland valley, there are very plainly marked moraines indicating the existence and retreat of local glaciers. The larger valleys of the Schoharie Kill, the East branch of the Delaware, and the Esopus Creek, also have their moraines, though not so well defined. Subsequent to the retreat of the great mass of the continental glacier these valleys were no doubt occupied by detached glaciers.

The above summary shows that the former existence of local glaciers in the mountains of New England and New York has been recognized, in some places as certain, in others as very probable. It is the purpose of this paper to describe a definite instance of local glaciation in the Catskills.

Location and topography.—The region covered by this paper lies in the northern part of the Catskills, roughly speaking at the junction of Schoharie, Greene, and Delaware Counties, and includes a part of each.[3] The Schoharie Creek, flowing northward, is the principal stream. It occupies a rather narrow, deep valley whose floor at Gilboa has an elevation of 1,000 feet, and at Prattsville, four miles south, 1,100 feet. South of Prattsville the mountains rise directly up from the valley to elevations varying from 3,000 to 4,000 feet, while north of that village is a dissected plateau with a general elevation of about 2,000 feet. All the mountains south of Prattsville, and the higher portions of the plateau to the north, are made up of Oneonta-Catskill red and gray sandstones and red shales, which give to the soil a very characteristic red color, easily distinguished from the bluish or yellow color of the northern drift.

About three miles west of Prattsville, at the head of Fly Brook, a tributary to the Schoharie is a large U-shaped amphitheater in the mountains, with the open side toward the northeast, and with a breadth of about two miles from crest to crest of its inclosing rim. On the south and southwest portions of the rim are the two highest peaks—Round-

[1] *U. S. Geological Survey, Third Annual Report*, p. 373.

[2] *American Journal of Science*, Series 3, Vol. XXV (1883), pp. 346–50.

[3] Gilboa sheet, U. S. Geological Survey.

top Mountain, 3,448 feet, and Bloomberg Mountain, 3,360 feet. Three spurs from the mountain divide the amphitheater into four minor basins. It is within this amphitheater that the evidence of valley glaciers may be seen.

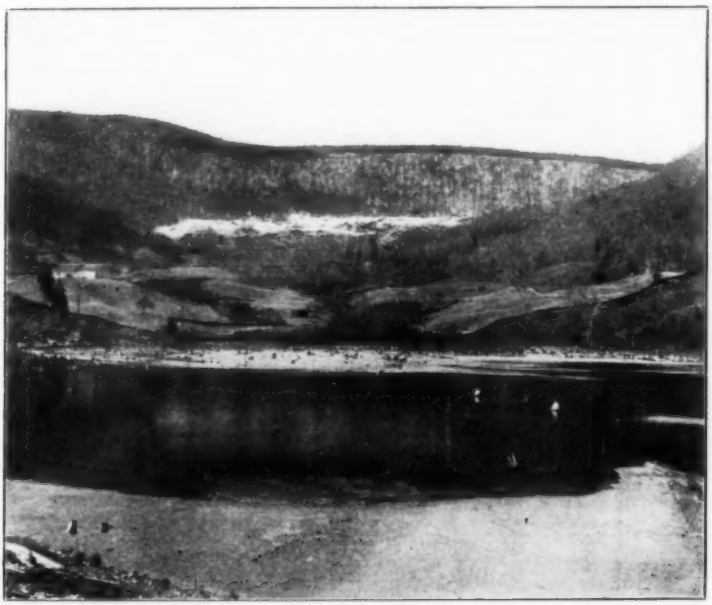


FIG. 2.—Looking up the valley from the terminal moraine. In the center is the hummocky moraine formed by the retreating glacier. One distinct loop may be seen in the middle of the valley. On the extreme right the lateral continuation of the terminal loop is shown running diagonally up the hillside.

VALLEY GLACIERS

In the central and largest of the four basins there lies a small lake[1] held up by a morainic loop which swings in a crescent across the valley, then diagonally up the hill slope on either side. (Fig. 1), taken from the mountain a little below the snow, shown in Fig. 2, shows the lake and moraine as they appear from the mountain side down which the ice moved. It also clearly shows the hummocky surface in the fore-

[1] The lake has been enlarged by a dam across its narrow outlet.

ground, and on the left the moraine loop curving diagonally up the hillside.

The moraine, which forms an irregular ridge at least 60 feet high in places, has a rather abrupt slope on the down-stream side, and from its terminus a somewhat gravelly deposit, evidently of outwash origin, stretches away down-stream. Above the lake, for a distance of half a mile, is a thick, hummocky morainic deposit showing one or two

FIG. 3.—A nearer view of the terminal loop. Its semicircular form is well shown.

fairly distinct ice-stands. This feature is shown in Fig. 2, taken from the terminal loop looking up the valley down which the ice came. On the extreme right of this picture the lateral continuation of the loop is shown running diagonally up the hillside (see also Fig. 1). Figs. 3 and 4 are nearer views of the lake and moraine seen from opposite sides of the lake.

The evidences of extinct valley glaciers in this amphitheater are not confined to the one basin just described. East of it are two basins

each of which had its glaciers. The first of these has a morainic loop just as perfect, though not so large, as the one which holds the lake. It shows even better the lateral moraines on each side running diagonally down the hill and joining in the terminal loop. Within this moraine, and concentric with it is another smaller, though very distinct, loop. Between these moraines and the mountain, the bottom of the basin is moraine-filled like that of the larger valley already described.

FIG. 4.—A view along the moraine front from the point where the loop joins the hillside. Above this point the lateral moraine continues for nearly half a mile up the hillside. Below, it swings in a beautiful crescent across the valley.

The second basin is less pronounced than the first, and contains, consequently, a less conspicuous, though perfectly distinct, moraine.

Between the terminal moraine and the mountain is a hummocky topography resembling that in the other basins.

The remaining basin, lying west of the lake, I did not examine closely. It is thickly wooded, and may or may not contain local moraines.

These morainic accumulations are composed almost exclusively of local material. In the course of a half-day spent in tramping over them, during all of which time a constant lookout for foreign rock fragments was maintained, I found only one stone, a small piece of gneiss, of other than local origin. This strictly local nature of the morainic débris, taken in connection with the fact that all the terminal loops are convex down-stream and all have distinct lateral moraines leading down to them from the hillsides, shows conclusively that for an explanation we must look to local valley glaciers, and not to the continental ice-sheet, or tongues from it, pushing up toward the mountain from the north.

The valley of Fly Brook, all the way from the lake to its junction, with the Schoharie Creek, a distance of three miles, suggests strongly the idea that it was once occupied for its entire length by a valley glacier. One and one-half miles below the lake, and about 20 rods below the schoolhouse, are exposures of rock by the roadside showing striæ running in a northeast and southwest direction parallel with the axis of the valley. Patches of moraine along the valley sides, the U-shape of the valley bottom, and a peculiar morainic deposit where Fly Brook joins the Schoharie, all suggest a valley glacier.

PROBABLE EXTENDED LOCAL GLACIATION

There is some evidence that south of Gilboa the Schoharie valley and its tributaries were for a long time occupied by ice moving northward and outward from the higher Catskills. The reconnaissance nature of my visit to this region did not permit me to gather evidence enough to fully substantiate this hypothesis, but there are many facts which strongly suggest it. The following show the nature of the evidence: (1) The local nature and red color of the moraines are very conspicuous. At Gilboa, in the Schoharie valley, is a deep morainic accumulation of distinctly northern drift, containing numerous pebbles and bowlders of limestone and crystallines, and having a decided yellowish color entirely characteristic of the northern drift, and very different from the red of the local rocks. Overlying this is a thick deposit of lake clay of the same yellowish color. At Devasego Falls, three miles farther south in the same valley, is a moraine of an entirely different character. It is convex down-stream; it consists largely of local,

red débris, and is overlain by several feet of *red* lake clay. South of Devasego Falls, in the Schoharie and its tributaries, the moraines are composed very largely of this local red material. (2) Moraines across the Schoharie valley and its tributaries are, apparently in every case, convex down-stream. This is especially well shown at Devasego Falls, along the Manor Kill west of Conesville, and along the Batavia Kill between Prattsville and Ashland. (3) There are lateral moraines leading into these loops in a direction indicating ice-movement, out from the mountains.

SUMMARY

The elevation and consequent low temperature of the Catskills would enable them to support glaciers while the surrounding lower lands were entirely deserted by the ice. In one valley at least, local glaciers *did* exist for a period of time long enough for the building of a morainic loop 60 feet high in places. Evidences in the Schoharie valley point toward quite an extensive movement outward and northward from the mountains.

TERTIARY AND RECENT GLACIATION OF AN ICELANDIC VALLEY

HENRY G. FERGUSON

During the summer of 1905 I had the opportunity of accompanying Dr. Helgi Pjetursson, the well-known Icelandic geologist, on his trip through the west and north of Iceland. Our primary purpose was the study of the sedimentary beds included between the lava flows of the Tertiary basalt plateau of the island. Dr. Pjetursson has made some remarkable discoveries concerning these sedimentary beds, the most interesting of which is the finding of glacial deposits—apparently indurated ground moraines—between the older lava flows. Dr. Pjetursson has already described these formations,[1] but as they are little known to American geologists, I propose to describe one of the areas where these beds are best developed, the Botnsdalr valley at the head of the Hvalfjord, about 30 miles northeast of Reykjavik.

The basalts forming the walls of the valley dip eastward at an angle from 5° to 10°, this eastward dip being constant for the whole western part of the island, except occasionally near the west coast, where the boundary faults of the island cause a westerly dip. These tilted basalts are called "regional" by Dr. Pjetursson, as being common to northern Scotland, the Orkneys, the Shetlands, the Faroes, Iceland, and western Greenland; in distinction from the "insular" basaltic lavas, peculiar to Iceland. These "regional" basalts are roughly divided into a lower or black group, which contains the "Surturbrandur" lignite and ash deposits, with Miocene plant remains; and the gray group, which, like the gray group of Ben More[1] in the Mull plateau, is the upper group in the Icelandic plateau. The latter is equally deformed, but is separated from the black by an erosional unconformity. The basalts of the Botnsdalr region seem to belong high up in the black group.

[1] Helgi Pjetursson, "Om nogle glaciale og interglaciale Vulkaner paa Island," *Det kgl. Danske Videnskabernes Selskabs Forhandlinger*, No. 4, 1904.

Except for this erosional unconformity, there is no evidence, such as any large unconformity or discordance of dip, to indicate any marked

FIG. 1.—Hvalfjord and vicinity. From Thoroddsen's Map of Iceland, 1900.

pause in the volcanic activity which built up the plateau. After the building of the plateau, and before the later glacial periods, came the movements which tilted these older basalts, forming a synclinal

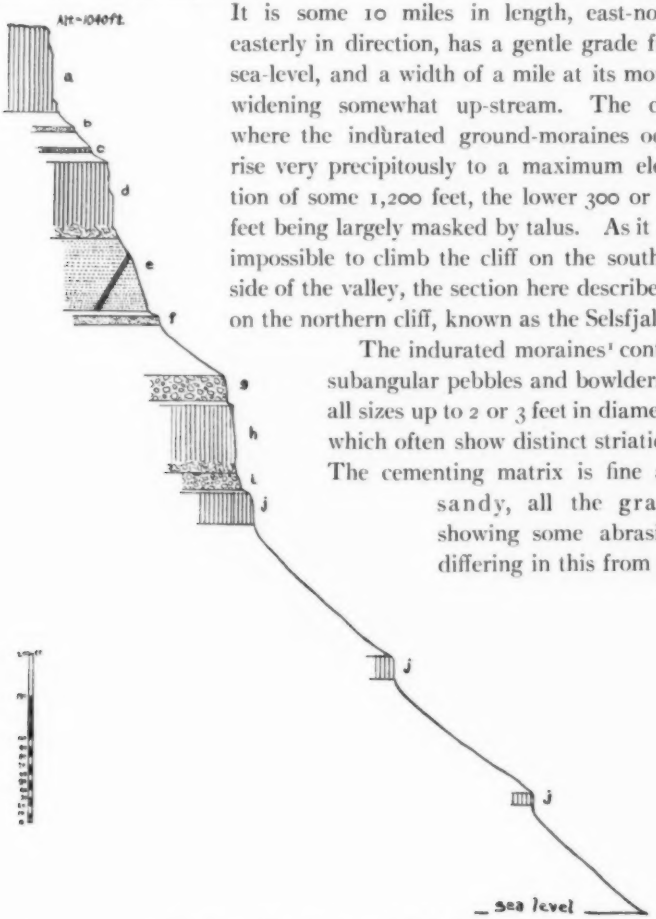
trough across the center of the island, where the most active of the present volcanoes are now found. This seems to have been accompanied by a certain amount of subsidence, and the present top of the plateau is in reality an old peneplain surface, the truncated edges of the tilted lava flows reaching about the same level. In regions where the dip is steeper than in the Botnsdalr, this gives a very noticeable serrate appearance to the sky-line. Whether this peneplain

FIG. 2.—Indurated moraine on the south shore of the Hvalfjord.

is tilted through later movements cannot be ascertained until better topographic maps are available, but the surface is much broken by later faulting. During this period came the extensive faulting, which greatly reduced the size of the island, and later the erosion of the fiords, these in part due themselves to faults. After the island had assumed roughly its present shape came the flat-lying lavas noted on Thoroddsen's map as "Doleritic lava (pre-glacial and glacial)," and several glacial periods. The time required for the peneplanation of the plateau, its uplift, and the present erosion seems to furnish additional evidence that the regional basalts are Tertiary in age.

[1] A. Geikie, *Ancient Volcanoes of Great Britain*, Vol. II, p. 215.

The Botnsdalr is a glacial valley, a continuation of the northern branch of the Hvalfjord, one of the east-west fiords of the Faxafjord. It is some 10 miles in length, east-north-easterly in direction, has a gentle grade from sea-level, and a width of a mile at its mouth, widening somewhat up-stream. The cliffs where the indurated ground-moraines occur rise very precipitously to a maximum elevation of some 1,200 feet, the lower 300 or 400 feet being largely masked by talus. As it was impossible to climb the cliff on the southern side of the valley, the section here described is on the northern cliff, known as the Selsfjall.



The indurated moraines[1] contain subangular pebbles and bowlders of all sizes up to 2 or 3 feet in diameter, which often show distinct striations. The cementing matrix is fine and sandy, all the grains showing some abrasion, differing in this from the

FIG. 3.—Main section on the Selsfjall.

a, basalt, several flows; *b*, flat-lying tuffaceous sandstone; *c*, third moraine; *d*, basalt, several flows; *e*, ripple-marked sandstone, cut by basalt dike; *f*, contorted tufaceous sandstone; *g*, second moraine; *h*, basalt, several flows; *i*, first moraine; *j*, basalt.

[1] For a description of Quaternary indurated moraines in southern Iceland, see H. Pjetursson, "The Glacial Palagonite Formation of Iceland," *Scottish Geographical Magazine*, Vol. XVI (1900), No. 5.

volcanic agglomerates and breccias, which contain small angular bits of black glass or "palagonite." The material is absolutely unstratified, thus differing from the "jökullhlaup" sediments described below, which show more or less distinct bedding. Dr. von Knebel,[1] however, describes indurated "jökullhlaup" sediments of the southern part of Iceland in terms which would be equally applicable to the beds I here describe as moraines.

FIG. 4.—Lower moraine and overlying basalt.

The basalt flows, averaging about 25 feet in thickness, are almost invariably brecciated near the lower surface, strikingly columnar in the center, and vesicular near the top. Where immediately covered by another flow, the upper surface is ropy.

The section on the Selsfjall is best explained by the accompanying illustrations. In the main section (Fig. 3) it will be seen that there are three morainal beds, usually covered by sandstone, instead of being directly overlain by basalt.

The lower ground-moraine is about 20 feet thick, and has no overlying sandstone. In consequence of being directly overlain by the basalt, the upper 3 or 4 feet of the bed are so thoroughly baked that the pebbles break off even with the matrix.

The second moraine, at the point shown in the section, is almost hidden by the talus. A few feet above the moraine is a small outcrop of a much contorted tufaceous sandstone. This contortion

[1] Dr. Walther von Knebel, "Vorläufige Mitteilung über die Lagerungsverhältnisse glazialer Bildungen auf Island etc.," *Centralblatt für Mineralogie Geologie und Paläontologie*, Jahrgang 1905, No. 17–18, p. 539. See also, H. Pjetursson, "Das Pleistocän Islands," *Centralblatt für Mineralogie, Geologie und Paläontologie*, Jahrgang 1905, No. 24.

seems inexplicable, except through the action of an advancing glacier, thus showing, with the earlier advance supplied by the ground moraine below it, a twofold advance and retreat of the ice during the period represented by this sedimentary series.

Above the contorted tufaceous sandstone is almost 100 feet of flat-lying ripple-marked sandstone, alternating between layers of fine clay and sandstone, the latter often spotted with pebbles of vesicular basalt. The clay layers were generally about an inch in thickness, while the sandy layers were often a foot thick and seemed to represent the annual flood of the stream. The ripple marks, by the steeper slope of the ripple ridges, showed a southwesterly direction of flow. In one place the sandstone was cut by a basalt dike which probably served as a feeder to some of the upper lava flows.

FIG. 5.—Ripple-marked sandstone above the second moraine.

The third moraine in this section did not exhibit any marked peculiarity. Like the second, it was overlain by tufaceous sandstone, in this case nearly flat-lying and not ripple-marked.

About 5 miles down the valley, to the westward from the main section, there is a good exposure of what is probably the second moraine of the first series. Here the overlying contorted sandstone is entirely lacking, and the sandstone above the moraine is more evenly bedded, shows no ripple marks, and is much more conglomeratic, containing several subangular bowlders, which at first sight gives it the appearance of morainal material.

Higher up on the cliff the third moraine is well exposed in a small gorge, and consists of about 10 feet of indurated moraine, contain-

ing some well-striated pebbles. It rests on basalt which has a polished surface, but is not distinctly striated. It is overlain by 20 feet of fine sandstone, which, in turn, is covered by extremely brecciated basalt.

Near this point at the top of the cliff, at an altitude of about 1,200 feet, remnants of a fourth indurated ground-moraine were found. A deep gorge prevented close examination of this bed, which differs slightly from the others. It rests directly on the truncated columns of a basalt flow, and seems to have sections of these same columns caught up in it, and but slightly rounded. The bowlders are larger than in any of the other ground-moraines, several being 3 feet in diameter. Where seen, it was not overlain by basalt; hence it is not necessarily Tertiary in age.

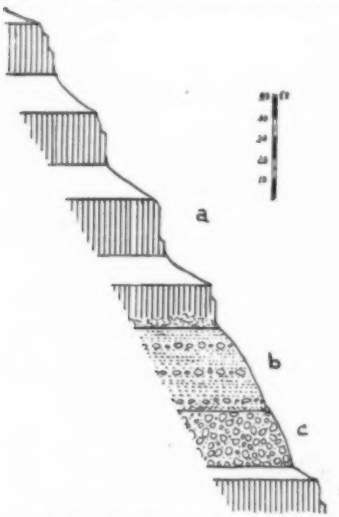


FIG. 6.—Second moraine, five miles to the west of main section

a, basalt, several flows; *b*, flat-lying sandstone and conglomerate; *c*, moraine; *d*, basalt.

Another, somewhat similar section appears on the face of the Botnselvens Klöft, a deep gorge entering the eastern end of the Botnsdalr on the northern side. The section is shown in Figure 8. It is impossible to attempt any definite correlation, but unless the beds have been disturbed by faulting, of which there is abundant evidence in the Skorradalr, a neighboring valley, the moraines here shown should correspond approximately to the third moraine of Fig. 3. The stratified material above the upper moraine appears to be overlain by basalt farther to the eastward. The two moraines have extremely uneven upper surfaces, as if there had been great irregularity in their upper surfaces as deposited, or as if they had undergone considerable erosion between the time of the retreat of the ice-sheet and the deposition of the sandstone and conglomerate above them. The upper surface of the basalt flow between the two

moraines is distinctly striated adjacent to the moraine, the scratches often running under the moraine itself.

On the southern side of the valley one of the higher moraines is nearly horizontal, with the gently tilted basalt flows resting against it, as if the moraine had originally been deposited on a sloping surface and had been subsequently buried by overlapping lava flows. Later tilting has given the position shown in Fig. 9.

There are certain points of similarity in these different Tertiary morainal beds which are worth noting:

The indurated moraines are weaker members of the cliffs than are the basalts, and hence tend to form shelves and have their lower contacts, the critical points of such beds, covered by talus. Whenever the contact is visible, as in the two points mentioned above, and in several other localities in the vicinity of the Hvalfjord, it is smoothed or striated.

FIG. 7.—Sandstone above the second moraine.

In nearly every case the moraine is overlain by bedded material, as if from deposits laid down by glacial streams during a retreat of the ice-sheet. No delta beds, so common in our glacio-fluvatile deposits, were seen, but perhaps these might be found if the sedimentary beds of the basalt plateau were studied in greater detail.

The lower surfaces of the basalt flows lying above the sandstone seem much more brecciated than those which rest on other basalt flows. This brecciation may have been caused by explosions due to the presence of standing water when the lava was fluid.

The inconstant nature of the moraines and sandstones is very noticeable; the beds change greatly in size in a very short distance,

and it is at present impossible to make any definite correlation between the sections.

The later glacial history of the Botnsdalr is illustrated by the following facts:

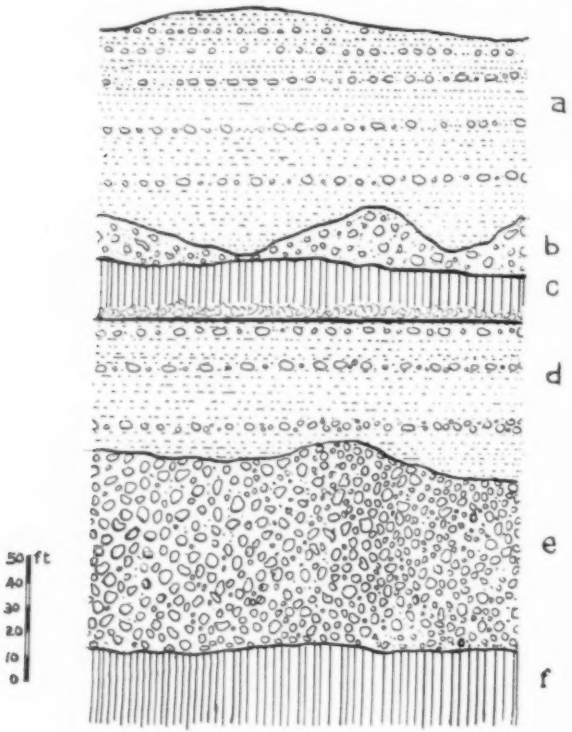


FIG. 8.—Section in Bothselvens Klöft.

a, sandstone and conglomerate; *b*, thin moraines; *c*, glaciated basalt, single flow; *d*, sandstone and conglomerate; *e*, large moraine; *f*, basalt.

In the eastern part of the valley, at a point where the cliffs are less prominent and the valley opens out considerably, is a glaciated hill, somewhat in the form of a ***roche moutonnée***, composed chiefly of tuffs, breccias, and a little lava, indicating by their radial dips the ruins of a volcano, younger than the valley. These tuffs, bomb-breccias and lavas were capped by a few feet of indurated moraine, evidently

inter-volcanic, as if it was even more thoroughly lithified than the indurated moraines in the Tertiary basalts. The pebbles were of vesicular basalt and, owing to their slaggy nature, did not show as good striations as the Tertiary moraines described above. The pebbles were all subangular, however, and a number showed striations.

A narrow gorge through this volcanic remnant showed an interesting section. The northern side was composed chiefly of tuff, volcanic breccias, and bomb-breccias, and thin lava flows, overlain by the indurated ground-moraine. These deposits rested on the older "regional" basalt, which showed distinct glacial striations, one rather faint set trending S. 15° W., the same direction as on the

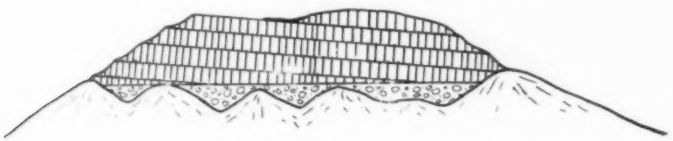


FIG. 9.—Contact of tilted basalts and upper moraine.

Botnsheidi, the plateau above the valley, showing the existence of an ice-sheet radiating outward from the center of the island; and the other more distinct trending S. 60° W., showing the action of a glacier following the present direction of the valley. The southern side of this hill has suffered most from recent glacial erosion, and here the indurated moraine seems to have been eroded off. Small pieces of a similar indurated moraine are found in the later terminal moraines at the mouth of the valley. The sedimentary beds, however, are different from those seen on the northern side of the hill. These are in part deposits, which Dr. Pjetursson believes to be due to a "jökullhlaup," literally "glacier-run," a flood caused by the sudden melting of vast quantities of ice, by a subglacial volcanic eruption. This material consists of very roughly stratified sandstone and conglomerate, of rapidly changing texture, varying from a hard clay, which, however, often contains subangular bowlders, to a coarse conglomerate. Often these beds show a faint and rather irregular cross-bedding. Large "scour and fill" unconformities are common, showing frequent changes in the stream-courses. At the point

shown in Fig. 10 a stream-bed has been filled with an angular unstratified volcanic breccia. These sediments rest on glaciated "regional" basalt which shows the same double set of striations as before.

Later glaciation of the valley is shown by recent polishing of rock-ledges, the striations running parallel to the direction of the valley, and by three well-marked frontal moraines. The westermost of these, at an altitude of about 150 feet, forms a barrier across the valley, except where cut through by the present stream; the other two are merely remnants on the sides of the valley. At the northern end of the valley is a large delta, perhaps 150 feet above sea-level, somewhat over a mile in length, which marks the head of a body of

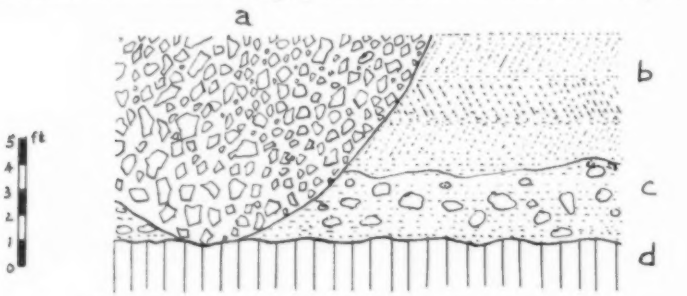


FIG. 10.—"Jökullhlaup" sediments and volcanic breccia.

a, volcanic breccia; *b*, roughly cross-bedded sandstone; *c*, conglomeratic sandstone; *d*, glaciated basalt.

water formed after the retreat of the last valley glacier. If this were a fresh-water lake, it is remarkable that its level remained constant long enough to allow such a large delta to be built, if the outlet stream was at a grade to enable it to do any effective down-cutting on the morainal barrier. The possible explanations seem to be either that, at the time of the formation of the delta, the sea stood at, or nearly at, the height of the top of the moraine, and that the gradual uplifting of the land allowed the stream to cut through the morainal dam and so drain the lake, or that the fiord itself formerly extended to the delta, and that the moraine was deposited in its shallow waters. These inferences are rendered more probable by the presence of old beaches and shell-beds at many places along the whole coast of Iceland, at elevations of from 50 to 300 feet above the present sea-level.

To sum up the glacial history of the valley; it is evident that, during the formation of the Tertiary basaltic plateau, there were several advances of a glacier. This glaciation was probably local rather than continental, as the indurated ground-moraines are not a common feature of the plateau. After the break-up of the plateau—and the isolation of Iceland—by faulting—the evidence goes to show that the region was again glaciated by an ice-cap, moving radially outward from the center of the island. This is suggested by the directions of ice-movement, given by professor Thoroddsen in his geological map of Iceland,[1] and by the direction of striæ on the Botnsheidi and the faint striæ of S. 15° W. direction found on the basalt under the pleistocene volcano. The ice-cap gradually retreated and became broken up, the remnant, sending down glacier tongues which eroded out the valleys, as is the case today with the Vatna, Myrdals, Eyafjalla, Lang, Dranga, and other great ice-fields of the island. During the period of valley glaciation, and after the excavation of the valley, a small volcano, possibly contemporaneous with Mosfell, a pleistocene volcano, 20 miles to the southeast, broke out under the ice, causing sudden floods, which have left their characteristic deposits. The glacier, however, recovered what was lost by this melting, as is shown by the indurated moraine above the glacial volcano, and in one of its recent stages advanced to the shores of the Hvalfjord and there deposited its best-marked terminal moraine. On the last retreat of the ice, this moraine probably formed a dam holding back the waters of a glacial lake. The sea, being nearly at the top of the moraine, prevented the drainage of the lake, until the uplifting of the land allowed the stream to cut through the morainal barrier; or else the sea-water of the fiord itself followed the ice on its retreat and the delta was deposited at the head of a former extension of the Hvalfjord.

[1] See also Th. Thoroddsen "Explorations in Iceland during the Years 1891–98," *Geographical Journal*, Vol. XIII (1899), No. 5, p. 493.

A PECULIAR FORMATION OF SHORE ICE

E. C. CASE
State Normal School, Milwaukee, Wis.

On January 27 of the current year the writer noticed that the ice along the Milwaukee shore of Lake Michigan from Lake Park to the city pumping-station, a distance of nearly a mile, was formed almost entirely of large snowballs such as are formed by children rolling the damp snow until it grows into a ball by accretion. The phenomenon was so peculiar that it led to a more careful study, and as the author has found no report of a similar condition, it seems worth while reporting.

The beach where the peculiar formation occurred is not wide, varying from only 3 or 4 feet to as much as 50 or 60; on the landward side it terminates at the bottom of an 80-foot bluff of glacial material, composed of the unstratified bowlder clay at the bottom and stratified sands and clays above, culminating in the "red lake clay" characteristic of the Wisconsin shore of Lake Michigan. Beyond the edge of the beach the water is very shallow for a considerable distance out, so that in time of even moderate waves bowlders of 3 and 4 feet in diameter appear in the trough of the waves 100 and more feet from shore. This bench has been formed by the waves cutting into the cliff and distributing the material on the adjacent bottom. During ordinary winters this shallow water freezes to the bottom very early, so that the ice-foot is far out beyond the usual water-line. The exceptionally mild winter of 1905–6 did not permit the water to freeze far out, so that at the end of January there was only a very narrow zone of shore ice, extending out not over 50–100 feet.

At the time of the author's visit the condition was somewhat as follows: There had been several very mild days with decided thawing, and the beach presented the appearance of a compact mass of balls of semi-solid ice, which upon investigation turned out to be masses of snow crystals which, by thawing and freezing

and by additions from the water of the lake, had grown to the diameter of a millimeter or two. The mass of ice had been broken along several parallel lines and displaced, showing a thickness of 3–4 feet; and this showed that the beach ice was a mass of the snowballs cemented by snow and frozen spray. The beach at this point runs slightly west of south, and the snowballs on the surface had

FIG. 1.—A group of large snowballs showing concentric arrangement of layers of dirt and snow.

been forced into prominence by the melting away of the softer cementing snow between them; moreover, about one-third of each ball was melted away on the south side. The southern faces which had suffered by melting presented a most peculiar appearance, which led to the recognition of the true nature of the balls. As shown in the figures, the melting had caused the contained dirt to accumulate on the surface, and it appeared as concentric rings. Close examination showed that this dirt was true beach sand and gravel. All the balls, varying in size from 3 inches to 3 or 4 feet, showed the same concentric arrangement, but in some the layers were alternately snow and clearer ice rather than snow and sand.

There seems but one explanation of this very queer phenomenon: the balls were rolled by the waves. The beach is a flat, smooth sand beach, and the water is very shallow for a considerable distance out. It seems that in some snowstorm early in the winter, before any ice-foot had formed, the beach must have been covered with 2 or 3 inches of a snow (the layers of the snowballs are from an inch to an inch and a half in their present compacted condition),

FIG. 2—A large snowball about 3 feet in diameter, half melted and showing concentric structure.

in a very damp and soggy state, perhaps filling the water adjacent to the shore with a heavy slush. The water must have been very close to the freezing-point, so that there was little or no melting of the snow as it came in contact with the water. Now, a rise of the wind would produce a surge which, moving up the beach and back, started the snow in motion, and as the snow was water-soaked, and too heavy to float with any buoyancy, it was pushed back and forth until it was compressed into a small mass which began to roll. There is no distinct nucleus to the balls either of harder snow or of small pieces of ice, as might be expected, but the center

seems the same as the outer parts. As the balls grew in size, it is evident that they rolled on the solid beach, gathering up a layer equal to the thickness of the snow on the beach, and including a thin layer of the sand and small gravel in the bottom of the layer.

The scarcity of the phenomenon seems amply accounted for by the peculiar conditions necessary for its production. There must be wide, flat beach such that the surge of the waves can carry them forward and back for a considerable distance; the water must be reduced to the freezing-point without the formation of an ice-foot which would hold the waves off the beach; and there must be a mass of soft, damp snow ready for the action of the waves.

RED MOUNTAIN, ARIZONA: A DISSECTED VOLCANIC CONE

WALLACE W. ATWOOD
University of Chicago

The location and form.—On the peripheral portion of the San Francisco Mountains, and about 30 miles northwest of the village of Flagstaff, Ariz., there is a small tuff cone, locally known by the somewhat appropriate name of Red Mountain. This cone bears the name of Mesa Butte on the San Francisco Mountain sheet of the topographic atlas. It rises between 700 and 800 feet above the general level of the plateau on which it stands, and at the summit is at least 7,750 feet above sea-level (Fig. 1).

When approached from the southeast or northwest, Red Mountain presents an even, dome-shaped form, such as is common to many of the cinder cones of the region, and if seen from either of these directions it would not attract special attention. On the southwest side a valley has developed, and the material taken from the mountain has been spread out at the base as an alluvial fan. On the northeast side there is a unique exposure, where the mountain has been so cut open that its internal structure is beautifully shown. From a distance (Fig. 2) few details of the exposure can be made out, but a number of layers appear which are roughly concentric and approximately parallel to the profile of the mountain. At closer range (Fig. 3) the concentric layers come out more strongly and they are seen to decline, not only to the right and left, but also toward the observer.

The material.—The material of Red Mountain consists of volcanic dust, cinders, lapilli, small crystals and fragments of crystals, a few bombs, many angular blocks, some agglomerate, and a bed of lava which is in part scoriaceous and in part compact. By far the greater amount of the material consists of the smaller products of volcanic eruption. About the base of the mountain, and high on the slopes, there are large quantities of black cinders and lapilli. They

were a relatively late contribution to the cone, and are unconsolidated. Within the mountain the fragmental material is cemented into a typical volcanic tuff. When seen from a distance, the color of

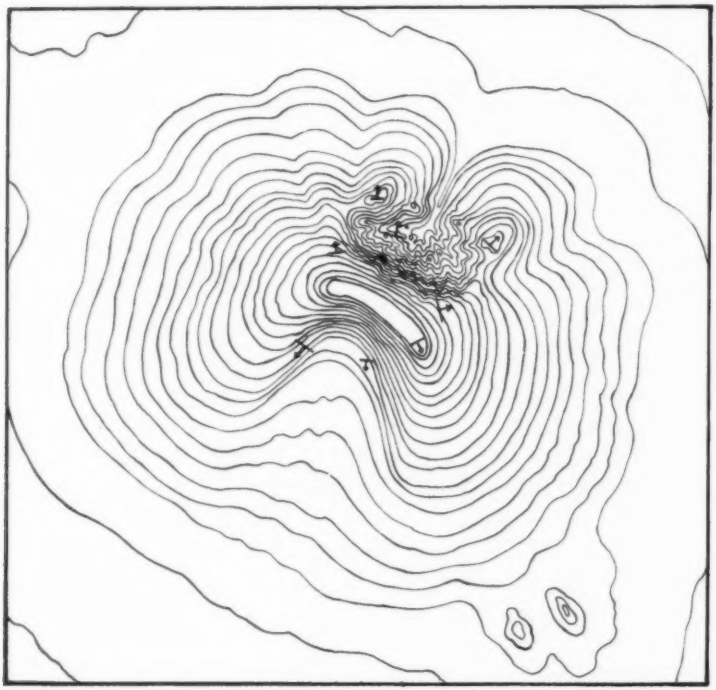


FIG. 1.—A topographic sketch of Red Mountain, Arizona, with the directions of dip and strike plotted at several points.

the tuff resembles that of the red beds, but at close range it is seen to be a combination of yellows and browns.

The angular blocks, which range up to 4 feet in diameter, are composed of a dark-red porphyritic andesite. The phenocrysts are labradorite feldspars, pyroxenes, hornblendes, and magnetites. The lava flow and agglomerate are exposed only on the southwest side of the mountain, about 100 feet below the summit. The largest out-crop shows a zone, 10 feet thick, of compact lava in which there

is a distinct flow-structure, between scoriaceous zones. The scoriaceous zone at the base is at least 5 feet thick, and that at the top is about 10 feet thick. At another exposure, 6 feet of compact lava overlie a scoriaceous zone 10 feet thick. Imbedded in the scoriaceous zone, at the base, there are huge blocks of compact lava. Both the scoriaceous and compact portions are porphyritic. The exposures of agglomerate are near the layer of lava, and associated with the surface of the flow.

Small crystals and fragments of crystals are exceedingly common in the tuff. Probably there is not a square foot on the surface of the tuff, as now exposed, where crystals could not be found. The chief minerals represented are plagioclase feldspars, pyroxenes, and hornblendes. The plagioclases have characteristic striations, they are clear and glassy, and range up to an inch in diameter. The pyroxenes and hornblendes are commonly jet-black, and vary in size up to three-fourths of an inch. The crystals are a part of the fragmental material ejected by the volcano, and were therefore formed in the magma before eruption. The formation of these crystals, as well as those in the angular blocks and in the lava flow, caused an increase in the gaseous pressure in the magma, and according to the suggestion of Chamberlin and Salisbury, may have been an important factor in causing the explosions.[1]

The gases occluded in the andesite and in the pyroxene crystals have been determined by R. T. Chamberlin. One volume of the rock gave 6.37 volumes of gas of the following composition:

H_2S	0.01
CO_2	80.38
CO	9.02
CH_4	4.72
H_2	1.84
N_2	4.00
	99.97

One volume of the crystals gave 1.11 volumes of gas of the following composition:

[1] Chamberlin and Salisbury, *Text-book on Geology*, Vol. I, p. 618.

H_2S	8.90
CO_2	62.62
CO	14.46
CH_4	1.30
H_2	7.01
N_2	5.71
	100.00

The structure.—The San Francisco Mountains and associated cones rest on the Colorado plateau, where Carboniferous limestones

FIG. 2.—General view of Red Mountain from the northeast.

appear at the surface. According to Dutton, the plateau was not reduced to the Carboniferous horizon until late in Miocene times.[2] The writer has reported evidence of Pleistocene glaciation in the main crater of the San Francisco Mountain,[3] and it is fair to assume that volcanic activities had ceased in the entire region by that time. The geologic age of these mountains is therefore probably late Tertiary. The cone under consideration appears to rest, in part at least, upon a lava flow that issued from the main crater or from

[2] Dutton, *Tertiary History of the Grand Canyon District*, Monograph II, U. S. Geological Survey, p. 221.

[3] "Glaciation of San Francisco Mountain, Arizona," *Journal of Geology*, Vol. XIII (1905), p. 276.

some fissure associated with the center of activities. This relationship indicates that Red Mountain was developed during the later, rather than during the earlier, phases of vulcanism in the region.

The general position of the layers of tuff has been referred to, and the directions of the strike and dip have been plotted at several points on the topographic sketch (Fig 1). The layers near the base, and as

FIG. 3.—Northeast side of Red Mountain, showing structure.

near the center of the mountain as it is possible to get, decline 4°. They are, probably, some of the ealiest deposits made about this vent. As the fragmental material accumulated, it formed steeper and steeper slopes about the rim of the crater, and today the exposures show an increasing dip from the base to the summit, passing gradually through angles of 5°, 10°, 15°, up to 20°. The major divisions in the tuff appear, from a distance, to be from 15 to 20 feet thick. On closer examination subdivisions may be recognized down to an average thickness of from one to two inches. Within a layer or bed of tuff there is no noticeable assortment of material.

Each explosion added a thin coating of fragments that were intimately intermingled in the air before falling to the mountain slopes.

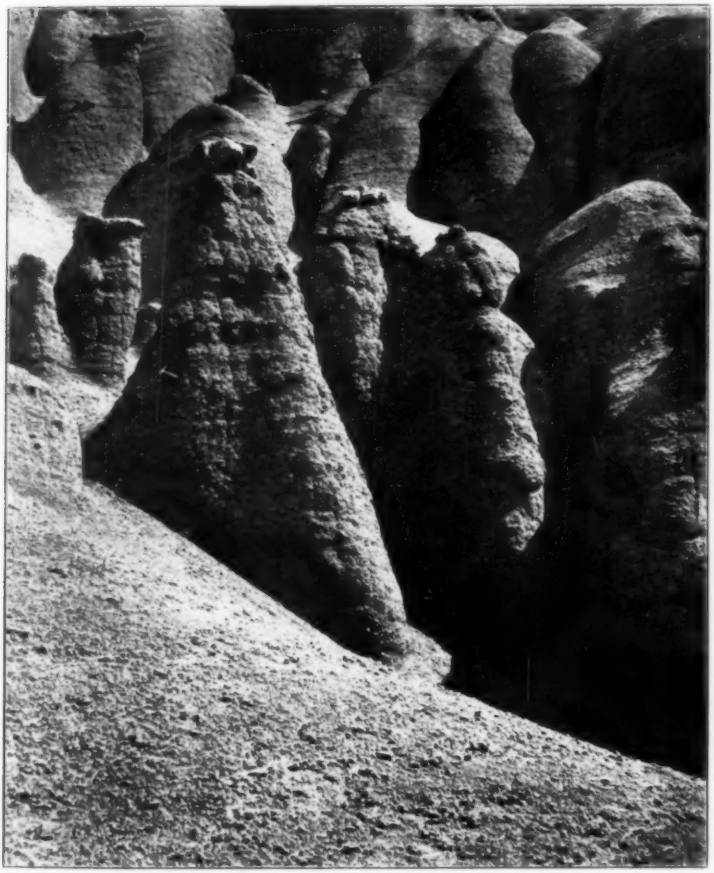


FIG. 4.—Close range view in Red Mountain, showing pillars of volcanic tuff capped by angular blocks of lava.

At very close range (Fig. 4) the surface of the tuff appears rough and the bedding is indistinct. Certain explosions contributed large quantities of angular blocks which now characterize different

horizons. In general, the contributions of angular blocks were greater during the later than during the earlier eruptions. At times true volcanic bombs were thrown out, which indicate that molten lava must have risen well up into the crater.

The lava which issued near the close of the period of growth overflowed to the southwest and descended but part way down the slope.

FIG. 5.—Looking west in Red Mountain. The layers of tuff come out clearly near the base, but are obscured on the upper portions of the slope by the general pitted condition of the surface. The pits are where great masses of lava have been weathered out.

The southwest portion of the crater rim was presumably lower most of the time, for the prevailing winds from that direction must have carried a large proportion of the ejected material to the northeast side.

The erosion.—Rain and running water have removed all traces of the crater, and the present summit is but a narrow crescentic ridge dividing the waters which operate on the southwest and northeast slopes. The erosion on the southwest side has been referred to with sufficient detail. On the northeast the mountain may be

entered through a narrow gorge. This gorge is not commonly occupied by a stream, but its form is such as to indicate that it was made by running water. Within the gateway the excavation in the mountain broadens out into an open amphitheatral form, and serves as an immense funnel concentrating the waters which fall on that side of the mountain.

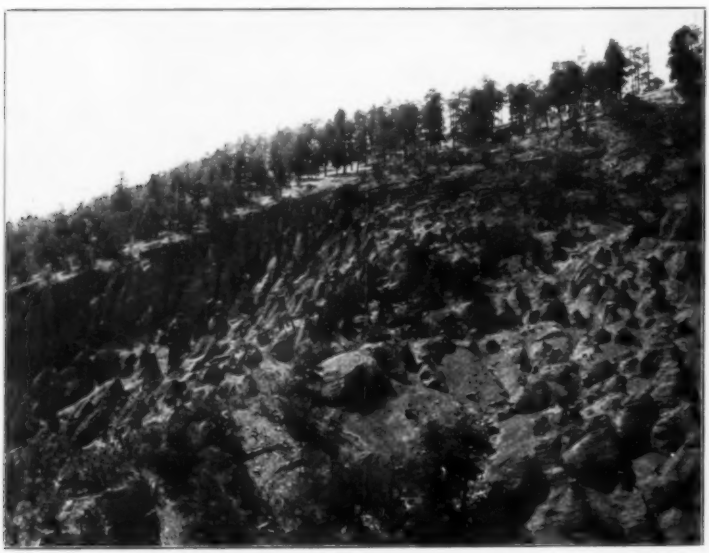


FIG. 6.—Looking east in Red Mountain, showing numerous pillars and mounds which have resulted chiefly from rain erosion.

The erosion-forms in the amphitheater resemble those common to bad lands. There are narrow winding passageways which end as box canyons; on projecting spurs there are sharp pinnacle-like forms capped with angular lava blocks; the walls are decorated with strangely irregular forms, and marked by great pits where large masses of lava have been weathered out. To the west (Fig. 5), the layers come out clearly near the base, but higher on the slopes they are indistinct. To the east there are numerous pillars and mounds in various stages of development (Figs. 4 and 6). Some of the pillars are just being separated from the main mass of the moun-

tain. Others have become isolated and stand 5–15 feet above their surroundings. Some appear to have recently lost their capstones and stand as unprotected spires. Others have long since lost the protection offered by the blocks that caused their development, and are now reduced to mounds. In portions of this area these mounds resemble an irregular grouping of old-fashioned bee-hives. The work of erosion goes on very slowly now, but may be assumed to have been more rapid during the moist climate of Pleistocene times.

A summary.—Based on the above data the history of Red Mountain may be sketched as follows: Late in the Tertiary period a secondary volcanic vent opened on the outskirts of the San Francisco Mountain center. A series of explosions occurred, building up a cone of fragmental material to a height of several hundred feet. The first material ejected fell on a relatively flat surface. As the cone grew in size, the fragmental material rested at higher and higher angles. Lavas rose into the crater, and volcanic bombs were formed. The winds carried much of the loose material to the northeast, building that portion of the crater rim highest. Late in the growth of the mountain a small amount of lava issued from the crater and flowed part way down to the southwest slope. Eruptions continued until the mountain rose about 1,000 feet above the plateau level. Based on the number of layers in the tuff, a conservative estimate of the number of explosions necessary to have built the cone is between 4,000 and 5,000. This estimate does not allow for any height above the present summit, and is therefore probably far below the correct figure.

Waters that were presumably associated with each eruption and more recent rains assisted in cementing the fragmental material together. Rain and running water have now partially dissected the cone, exposing the successive layers of fragmental products and developing a large variety of peculiar forms. The remarkable exposure on the northeast side extends nearly to the core of the mountain.

CARBONIFEROUS FORMATIONS OF NEW MEXICO

CHARLES R. KEYES

Several features contribute to make the Carboniferous section of New Mexico the most noteworthy of the American continent. Its enormous thickness, the strictly marine nature of its sediments which constitute it the most imposing limestone plate among the known formations of the country, the feeble development of extensive shale beds so familiar elsewhere, the total absence of workable coal-beds which are the one feature of all others that is usually characteristic wherever the rocks of this age are found, the existence of a number of great planes of unconformity clearly indicating enormous erosion intervals, and the great abundance of organic remains, are some of the more salient points contrasting the Carboniferous of New Mexico with the sections of the same system elsewhere.

It has been unfortunate that the notes which have been made during the past half-century upon the Carboniferous rocks of the southwestern United States have been so meager, and so disconnected, and the publications in which they have appeared so widely scattered. From the literature alone, practically no correlation of separated sections has been possible. Confronted with these exceptional conditions, it soon became one of the main objects in the course of the geological survey of the New Mexican region to examine not only all of the Carboniferous exposures, as far as possible, and to correlate them in the field, but from the point of vantage thus gained to connect with these broader observations the fragmentary notes previously published.

The great thickness of the "Upper Carboniferous limestones" of the southern Rocky Mountain region has always been a matter of comment among all those who have traversed this part of the country. Few of these persons have ventured to put the measurement of these great limestones above about 2,000 feet. That the connected section of the Carboniferous strata as represented within the boundaries of New Mexico, indicated a thickness which was

actually so enormous as it is, and as the recent measurements clearly show, was never thought of. This maximum thickness is now known to exceed 6,000 feet. Six great and important series have been differentiated. As now recognized, they are, with their respective thicknesses, as follows:

Unconformity	
Cimarronian sandstones and shales	1,000 feet
Unconformity	
Guadaloupan limestones	2,500 "
Maderan limestones	700 "
Manzanan limestones	1,300 "
Unconformity	
Ladronesian shales and sandstones	100 "
Unconformity	
Socorran limestones	500 "
Unconformity	

Of these, one series is Early Carboniferous, and is found only south of the central portion of the state; two are of Mid-Carboniferous age; and three belong to the Late Carboniferous.

With the schematic, or standard, section of the American Carboniferous series, as represented in the Continental Interior province, in Missouri and Kansas (II), may be paralleled the section of the Southwestern province represented by New Mexico (I), and also the eastern section of Pennsylvania (III), as usually given.

	TIME DIVISIONS	PROVINCIAL SERIES		
		I	II	III
CARBONIFEROUS	Late	Cimarronian Guadaloupan Maderan	Cimarronian Wanting Oklahoman	Wanting Wanting Permian
	Mid	Manzanan Wanting Ladronesian	Missourian DesMoines Arkansan	Pennsylvanian
	Early	Socorran	Mississippian	Pocono

Comparing in a general way the New Mexican succession of the Carboniferous formations with that of the Upper Mississippi valley, there is at once noticeable in the first-mentioned section a rela-

tively much poorer representation of the Early Carboniferous sediments, an almost entire absence of the early Mid-Carboniferous shales, a very much greater development of middle and late Mid-Carboniferous marine beds, and a very great expansion of the middle Late Carboniferous marine deposits, while the sediments of the closing period are very much the same in both.

The thicknesses of the various formations are readily determined, usually in single unobscured vertical sections displayed in the fault scarps of the block-mountains which rise 3,000 to 5,000 feet above the plains at their bases, giving continuous outcrops that for unbroken extent are nowhere in the world surpassed.

The marine nature of practically the entire Carboniferous sequence, as represented in New Mexico, contrasts it strongly with the sections of the central and eastern United States. The main body of limestones composing the Manzanan and Maderan series were early recognized by government explorers as "Upper Carboniferous limestones." These two series and some other beds, taken together, have more recently, especially in the Grand Canyon district, eastern Arizona, and western New Mexico, generally gone under the title of the Aubrey limestone; and in western Texas, under the vaguely defined name of the Hueco limestone. Over the greater part of all of these regions the formation passing under a single title is easily separable into three or four distinct formations having serial rank, and each again is locally subdivisible.

The general absence of shales and coal-beds in the Carboniferous formations of the New Mexican region is one of its most striking features, particularly to one who has been accustomed to the great beds of shales, shaly sandstones, bituminous beds, and coals of the East. The horizons at which these deposits could be naturally expected are immediately beneath the great limestone plate having the Manzanan series for its base. There is, however, at this stratigraphic level a great plane of unconformity which is of very wide extent, and which represents a profound erosion interval.

If extensive shales ever existed here, and they evidently have, they have been almost entirely swept away. That there were once important coal-measures deposited on this old erosion surface is

amply demonstrated by isolated deposits which still remain in protected localities, accidentally preserved through dropped fault-blocks. For example, near Socorro there have been recently discovered several such remnants of coal-bearing shales, both in the Sierra Ladrones and to the east of the town. The deposits of the latter rest in marked unconformity upon the rocks beneath, and appear to have unconformable relationships with the strata above. Although only about 100 feet of these shales now remain in the locality mentioned, the recognition of their presence, their character, and their location is very likely to lead soon to discoveries of very much greater developments. For this reason, and on account of the important period which the deposits manifestly represent, they have been called the Ladronesian series.

The principal or great planes of unconformity which have been made out are five in number. They all represent great erosion intervals. The only similar phenomenon in the Mississippi valley at all comparable to any one of them is the unconformity at the base of the DesMoines series, in Iowa, Illinois, and Missouri; and it is now known that during this interval the entire Arkansan series of shales, over 10,000 feet in thickness, was laid down. With two exceptions, all of the six series recognized are separated by great unconformities, and there are also unconformities at the base and at the top of the Carboniferous sequence. Besides these five unconformities of wide extent, there are a number of local phenomena of similar character, the exact magnitude of which is as yet not fully determined.

The character and location of some of these unconformity horizons in the New Mexican field suggest their presence in the Kansas, Oklahoma, and Texas sections where they have not before been suspected. And this accounts for some hitherto inexplicable observations that have been made in those states.

Organic remains of the entire Carboniferous section are, with few exceptions, strictly marine types. They are abundant throughout the whole sequence, except perhaps at the very top. In most localities where the rocks are well exposed fossils are as plentiful as they are in the more familiar sections of eastern Kansas. Some of the faunas are totally unlike anything described from other parts

of the American continent. Their definition, range, distribution, and comparison with those of other provinces promise interesting and instructive results. In the New Mexican province a most inviting and unique field awaits students of Carboniferous life.

Enough is now known of the fossils to enable their general affinties to be made out with reasonable certainty. Much that is new is to be found among them. The careful determination of the range and distribution of the various faunas and faunules is necessary before exact comparisons can be made with those of other provinces, and correlation made according to biotic methods alone.

The serial subdivisions of the New Mexican Carboniferous succession is based partly upon biologic data, but largely upon direct stratigraphic grounds. Correlation with the Kansas section has been mainly by organic content, and secondarily by general formational relationships. The correspondence of the two perfectly independent records is close to a degree that is quite remarkable.

As already intimated, six distinct and easily recognizable subdivisions of the great succession of strata have been defined. Taxonomically they hold the rank of series. Special mention of the numerous minor formations which go to make up these series need not be made at this time. However, the several series may be briefly characterized.

The basal series to which the title Socorran has been given comprises all of the Early Carboniferous sediments in the Southwestern province. It corresponds to the original Mississippian series of the Continental Interior province, though it manifestly does not include so much. According to present faunal and stratigraphical evidence, its equivalent in the Upper Mississippi valley is the Chouteau and Burlington limestones. A prolific Lower Burlington fauna, including most of the most typical crinoids, is found at Lake Valley. Nothing higher than the strata containing the Lower Burlington fauna has yet been found in this region. Whether this later part is present and concealed, or actually absent altogether, cannot be at present stated. A profound erosion plane bevels off all known Early Carboniferous strata; hence it is quite probable that considerable more of the basal portion of the general section will sooner or later be brought to light in this region.

Ladronesian is a title applied to the only coal-bearing formation of the entire section under consideration. This series now exists only in remnants of a formation that was once evidently quite extensive. It consists chiefly of shales and sandstones with thin coal-seams. The formation rests unconformably upon the rocks beneath. Profound Carboniferous erosion has all but completely obliterated all evidences of its existence. The shales carry interesting coal plants, chiefly of lepidodendrid types. There is but small doubt that the formation is the representative of the Arkansan series of the Ozark region.

Resting unconformably upon all rocks beneath is the great blue and gray limestone plate which is that portion of the Carboniferous section with which most travelers have come into contact, and which is most familiar. Farther west the lower portions have been called the Aubrey limestones. To the south the major portion is known as the Hueco limestone. The upper part of this unbroken limestone sequence is absent over all of Arizona and New Mexico, except in the extreme southern part of the latter. Faunally, as well as stratigraphically and lithologically, the great plate is separable into three distinct sections. These three formations, which have serial rank, are the Manzanan, the Maderan, and the Guadaloupan series.

The Manzanan series is composed chiefly of massive blue and gray limestones with some thin gray shale layers. The fossils are essentially those which characterize the Missourian series of eastern Kansas. In the northern half of New Mexico this formation reclines directly upon the eroded surface of the Acrhæzoic and Proterozoic crystallines.

Above the Manzanan series, and apparently continuous with it, is a lithologically similar formation, though it is more of a gray color, and often having dark layers intercalated. It is termed the Maderan series; and it carries the so-called Lower Permian fauna of Kansas. It is paralleled approximately with the Oklahoman part of that succession. This hard limestone formation is the rock-floor over a considerable portion of northern Arizona and west-central New Mexican region. It is this formation that manifestly constitutes the chief part of the Hueco formation of Trans-Pecos Texas.

The Guadaloupan series is unique. In all the American continent there is no formation with which it may be compared, or with which it may be geologically correlated. At the typical locality it consists of a thick sandstone at the base, surmounted by over 1,000 feet of white massive limestone. So far as known, the formation is exposed only on the southern border of New Mexico. It has suffered enormous erosion, and has been entirely removed from the central New Mexican area, over which it no doubt at one time extended. The extensive faunas which it carries have no known counterparts in the Kansan section. They are all younger than any of the described faunas of Carboniferous age in that district, yet older than the earliest Mesozoic faunas. The greatest development of the formation is found in the Guadaloupe Mountains, in southeastern New Mexico, which form the western border of the broad Pecos valley. Fossils were described from this locality by Shumard more than half a century ago. Nothing more was known of them until quite recently, when Girty identified a large number of Shumard's species from this place and many others. The relationships of the formation with the other parts of the Carboniferous section of New Mexico have never been known until quite lately.

Along the east slope of the Guadaloupe range the Carboniferous Red Beds, or Cimarronian series, appear to overlie the white limestone series in marked unconformity. Its position in the Kansas section probably is marked by a hiatus at the bottom of the Cimarronian beds of that region.

The great fault-scarp at Guadaloupe Point presents a sheer precipice of more than 3,000 feet in height. The lower 200 feet appear to be the uppermost dark limestone of the Maderan series (Hueco limestone of Richardson). Then follow 1,500 feet of light-colored, coarse-grained massive sandstone—the Eddy formation,[1] which extends northward through Eddy County, New Mexico. The white Capitan limestone forms the upper 1,000 feet.

The Carboniferous Red Beds of New Mexico appear to be the western extension of the Cimarronian series of central Kansas.

[1] Richardson's name of Delaware formation for this bed is preoccupied for a well-known Ohio formation.

They rest unconformably upon the older rocks and have the triassic Red Beds reposing in a very marked unconformable relations upon them.[1] The formation has a very wide geographic distribution, and is, for the most part, unfossiliferous.

The complete sequence of formations composing the New Mexican Carboniferous section may be tabulated as follows:[2]

	Series	Formations	Rocks
Carboniferous System — Permian	Cimarronian	Moencopie ———— ? ———— ?	Shales Sandstones Shales
	Guadaloupan	Capitan Eddy	Limestones Sandstones
	Maderan	———— ? ———— ? ———— ?	Limestones Limestones Limestones
Pennsylvanian	Manzanan	Mosca Coyote Montosa Sandia	Limestones Sandstones Limestones Shales
	Ladronesian	Alamito	Shales
Mississippian	Socorran	Lake Valley Berenda	Limestones Limestones

[1] *American Journal of Science* (4), Vol. XX (1905), pp. 423–29.

[2] The wavy lines represent unconformities.

EDITORIAL

The suggestive article by Professor Schwarz relative to a former land connection between Africa and South America (p. 81) furnishes an excellent illustration of the vital dependence of our studies of most large problems on fundamental conceptions of the early states of the earth. An essential part of his argument from the nature of the rocks of the oceanic islands hangs upon theoretical views as to what the specific gravities and the structures of the oceanic and continental portions of the crust, respectively, should be, under alternative assumptions relative to the configuration of the ocean surface. If the average specific gravities of the sub-oceanic and of the sub-continental sectors were the same, the waters of the hydrosphere would be drawn up about the continental masses, and would add their gravity to that of the continents, and thereby increase the differential stresses within the lithosphere and tend to depress the continents. To sustain stresses of such magnitude, the rigidity of the lithosphere must be assumed to be very effective, and the agencies of elevation must have worked against these stresses ever since the continents were formed.

If, on the other hand, the sub-oceanic rocks are sufficiently higher in specific gravity to counterbalance (with the aid of the overlying oceanic waters) the weight of the continental protuberances, the surface of the ocean must be more nearly spheroidal and the lithosphere much less affected by differential stresses.

To test these alternative hypotheses in the most direct and positive way, there is need that geodetic measurements of the ocean surface be extended outward from the continents on chains of islands as far as possible, and that pendulum observations be made on the oceanic islands and on the open ocean itself, so far as practicable.

But even if such determinations were at command, there would still be need, whatever their results, to take careful note of the different inferences that legitimately arise from alternative views of the earth's genesis, if we are to proceed on safe grounds of interpretation. The criteria deduced by sound reasoning from a molten

earth do not altogether hold if the earth was built up by gradual accretions and was solid at all stages.

If the earth was once molten, it is a fairly sure inference that all the deeper portions were affected by essentially the same specific gravities at the same distances from the center. Only at and near the surface is it probable that there was much differentiation of specific gravity in the original liquid spheroid, if indeed much even there. If, therefore, the geodetic determinations were to show that the oceanic surface is nearly spheroidal, and the pendulum observations were to show that the crust is in approximate isostatic equilibrium in a general way, neglecting local inequalities, it is a firm inference that there must be a rather marked difference in the specific gravities of the sub-oceanic and of the continental portions of the crust respectively, as Professor Schwarz has indicated, for the sub-oceanic crust, plus the water that is on it, must counterbalance the continental protrusions. The amount of this difference in specific gravity *must depend on the depth to which the differentiation of rock extends.* For example, if the continental protrusions be taken to average three miles in height above the oceanic bottoms, and the lower limit of differentiation of specific gravities be assumed to be reached at a depth of six miles below the average surface, the specific gravity of the differentiated portion of the sub-oceanic crust, three miles thick, must be enough, with the aid of the overlying water, to counterbalance the six miles of the differentiated continental shell, from which it is obvious that a very high specific gravity for the sub-oceanic rock is required. If the differentiated portion of the crust were no thicker under the continental surfaces than under the oceanic, the differences of specific gravity would be still greater. If the limit of differentiation be taken at the greater depth of nine miles below the average surface, six miles of rock and three miles of water on the oceanic side must counterbalance nine miles of rock on the continental side, in which case a less, but still a pronounced, difference in specific gravity is required to meet the conditions of the case. For any such moderate depth of differentiation as would probably arise in the development of a crust upon a molten sphere, a marked difference between the specific gravities of the sub-oceanic and of the continental rocks seems to be implied,

and this furnishes a working basis for such inferences as are discussed in Professor Schwarz's article. These are representative of the lines of interpretation that have most prevailed under the dominance of the doctrine of a primitive molten condition.

If, however, the earth be supposed to have been built up by the accretion of planetesimals, with a concurrent differentiation into continental and oceanic segments through the agency of weathering and transportation, as recently suggested,[1] the differentiation of specific gravities between the sub-oceanic and the sub-continental segments may extend to a possible depth of 1,500 to 1,800 miles. With such a depth of differentiation, a difference of surface protrusion of three miles only requires an average differentiation of specific gravity of about one-fifth of one per cent., a difference quite beyond detection lithologically. If the depth of effective differentiation were much less, as is not improbable, the average specific gravity of the sub-oceanic rocks would still need to be only slightly greater than that of the sub-continental ones to meet the requirements of the case.

When we consider the wide range of variation that was likely to be introduced by selective fusion and by the magmatic differentiation of the extruded rocks of both the sub-oceanic and the sub-continental segments, it does not seem safe to infer that any specific class of rocks would be excluded from either area. The probable differences between the rocks of the two areas would be detectable merely by a greater preponderance of heavy rocks in the sub-oceanic areas and of lighter ones in the continental. If a compilation of available data, made some years ago at the suggestion of the writer, is to be trusted, the preponderance of basic rocks in the extrusions of the oceanic volcanoes, present and past, is quite as high as the planetesimal hypothesis requires, and the discovery of a notable percentage of granitic and other acidic rocks is quite consistent with this hypothesis.

Under the planetesimal hypothesis the segments now beneath the ocean were, at an early stage, parts of the land surface alike with the continental segments. They are presumed to have been gradually converted into ocean bottoms by surface differentiation, leading

[1] Chamberlain and Salisbury, *Geology*, Vol. II, pp. 106–11.

on to greater depression, the volume of the hydrosphere meanwhile increasing and assisting in the submersion. The portions now submerged were presumably affected by reliefs not unlike those of the continental portions at like stages of evolution. In the course of their gradual submersion, the more protuberant swells and ridges are presumed to have stood forth from the growing seas as variously shaped lands which doubtless had a dominant tendency to elongated swells of ridge-like aspect, such as now affect the ocean bottoms and are being brought out more and more as soundings multiply. Not that all are necessarily of this class, however. In the slow process of their submergence, these swells and ridges were doubtless subject to denudation and circum-decomposition, as are other lands, and hence are similarly attended by sedimentary rocks. Some of these may have been submerged only in the later deformations of the earth's body, those of the Tertiary period perhaps, and previous to this they may have constituted bridges between the continents, and thus have satisfied the requirements of biological data, if these are indeed requirements. The loss, through deformation, of such bridge-connections of comparatively limited area and of moderate depression makes a relatively small demand on dynamic agencies and involves the withdrawal of a relatively small volume of water from the continental platforms. On the other hand, if vast continents be supposed to have arisen from the depths of the Atlantic, Pacific, and Indian Oceans, and to have again subsided, not only is a heavy tax laid on dynamic resources, but great volumes of displaced water must be accounted for in a complete hypothesis. We can no longer leave these considerations out of account as in the past, for the days of legitimate appeal to *terrae incognitae* are over.

If the hypothesis of a relatively thin shell shearing over a solid substratum, which seems to be forced upon us by a study of the folds of the corrugated mountains, be entertained,[1] the occurrence of foliated rocks at shallow depths beneath the oceans, as well as the continents, is to be assumed, though perhaps their extent and degree of development may be inferior. These foliated rocks may have as wide a range of lithological characters as the igneous rocks of the sub-oceanic crust which, as we have seen before, under the

[1] Chamberlin and Salisbury, *loc. cit.*, pp. 125–32.

planetesimal hypothesis may have a range little short of that of the continents. The existence of various gneisses and schists is not, therefore, in itself discriminative.

It is not improbable that, in time, the notable chain of islands that now skirt the eastern border of the Asiatic continent from Sumatra to Kamtchatka, standing along the outer border of the true continental platform, will be degraded and a portion of their material carried toward the mainland and re-deposited, and that this, conjoined with continental detritus, will at length fill up the intervening seas with stratified rocks, and thus extend the mainland eastward to the vicinity of these islands. In the meantime, sea encroachment, downward flexure, and the other agencies that affect the borders of continents[1] may have brought about the submersion of the sites of the islands themselves, in which event the border formations of the continent will present the same evidences of oceanward derivation of material that some of the coast formations of the continents do today. It is obvious, however, that, in this case, the phenomena will not imply a lost continent or any radical change in the configuration of the lithosphere, or even of the continent; much less will it afford evidence adverse to the essential permanence of the continents.

The intent of these suggestions is not to enforce any particular interpretation of the extremely valuable and suggestive data afforded by the oceanic islands, nor indeed to imply the limitation of alternative hypotheses to those here mentioned, but rather to emphasize the fact that the hypotheses employed in these inquiries, as in most others of a far-reaching nature, need to be traced back scrupulously to their sources, and to be put into comparison with other hypotheses, so that the true values and the limitations of the criteria employed may be made apparent, and their dependence upon fundamental hypotheses may be brought forth into sharp definiton and working application.

T. C. C.

The article in this number of the *Journal* on the Tertiary glaciation of Iceland possesses much interest for students of glacial geology

[1] *Op. cit.*, Vol. III, pp. 518–30.

in this country; but it should perhaps be pointed out that the Tertiary age of these morainic formations is not to be accepted, except on the basis of the most irrefutable evidence, and evidence of this sort is not cited in the article. The glacial deposits are interbedded with lava, and since the lava has been thought to be of Tertiary age, the moraines are inferred to be of Tertiary age. If the first of these conclusions is correct, the second is; but, so far as the evidence cited in this paper is concerned, the argument would seem quite as plausible if stated the other way, namely: Since the sediments interbedded with the lavas are glacial, they are Pleistocene; the lavas interbedded with them are therefore Pleistocene. Indeed, the presumption is strongly in favor of this statement, since abundant lavas of Pleistocene age are known, and no glacial formations of Tertiary age in any part of the earth are known, unless these constitute the exception. If they are really of Tertiary age, the fact is most significant, since it will call for a revision of present opinion concerning the climate of some part of the Tertiary period.

On the other hand, great deformations, great erosion-unconformities, and great physiographic features due to erosion have been developed since the close of the Tertiary, and igneous eruptions of consequence are known to have taken place, in America at least, since the Tertiary period. Accumulating evidence makes it clear that the rather common conception that the Pleistocene period was a very short one, must be abandoned. The evidence is now altogether adequate to show that the period was long enough for changes and events far greater than those which have taken place in Iceland since the inter-lava drift of that island was deposited.

R. D. S.

Reviews

Les tremblements de terre et les systèmes de déformation tétraédrique de l'écorce terrestre. ("Earthquakes and the tetrahedral deformations of the globe.") Par M. Montessus de Ballore. *Annales de Géographie*, No. 79, XV, 1–8, Paris, 1906.

Six months ago we called attention in this *Journal* (Vol. XIII, p. 462) to a notable paper by M. Montessus de Ballore upon the distribution of earthquakes. The author of that article has another in the *Annales de Géographie* for January, 1906, upon "Earthquakes and the Tetrahedral Deformation of the Globe," which is well worthy of especial attention in connection with the general subject of earthquakes and their distribution. Evidently the theory of the tetrahedral form of the earth — a theory so much favored by M. de Lapparent and by Michel-Lévy — is regarded by the author as worthy of serious consideration in connection with the study of the distribution of earthquakes. The following are the general conclusions formulated in the course of the article:

1. Considering the matter from a purely geographic point of view, earthquakes occur about equally and almost exclusively along two narrow zones that follow two great circles of the earth: the Mediterranean (or Alpino-Caucasian-Himalayan) circle, with 53 per cent. of the recorded shocks, and the circum-Pacific (or Ando-Japan-Malay) circle, with 41 per cent. of the shocks.

2. These seismic zones coincide exactly with the geosynclinal zones of the secondary epoch which during the Tertiary were thrown into mountain chains or geosynclines by the foldings and displacements.

3. The folded structure of the geosynclines is seismically unstable, while that of the tabular continental areas, on the contrary, is stable.

4. Finally, it is concluded that the existence, well established by observations, of two great circles of maximum seismic unstability affords no argument in favor of the theory of the tetrahedral deformation of the globe. On the contrary, it would be surprising if there were no relations between the earthquake regions of the earth and the elements of the tetrahedron, f such a solid really determined the most general movements of the surface of this planet.

It may be added by way of postscript, and for the benefit of students

of seismologic phenomena, that a new volume of five hundred pages by M. Montessus de Ballore, entitled *Les tremblements de terre*, has been recently published at Paris. In the preface M. de Lapparent directs attention to the great statistical value of the author's catalogue of earthquakes, and to the fact that he has brought seismology into its relations with geologic structure.

J. C. BRANNER.

The Linear Force of Growing Crystals, and an Interesting Pseudo-Solid. By G. F. BECKER AND A. L. DAY. Proceedings of the Washington Academy of Sciences, Vol. VII (1905), pp. 251–300.

About six months ago a modest paper, filling only five octavo pages, was published by George F. Becker and Arthur L. Day upon the "The Linear Force of Growing Crystals."[1] The writer has looked in vain for expressions of appreciation of this important piece of work.

Evidences of the linear force of growing crystals have long been familiar to geologists, but while the process of growth seemed clear enough from field observations, the demonstration of it and its quantitative determination have hitherto been altogether lacking, while the writer's efforts to interest chemists and physicists competent to deal with the problem have failed of success for twenty years. Discussions of the origin of secondary veins usually proceed on the theory of cavities, or of the replacement of one mineral by another. So far as we now recall, not one of the many writers on this much-discussed subject has ventured the suggestion that the growing force of crystals may have thrust apart the rock walls, and thus made room for the veins in the very process of formation. A few geologists have suggested that some such force operated in the formation of veins, but these are so few, and their suggestions have been made with such apparent hesitation, that little or no attention has been paid to them by the more voluminous writers upon ore deposits.

In 1882 Chamberlin recognized the displacing force of growing crystals of sphalerite, galenite, and pyrite in the ore deposits of southwestern Wisconsin, as indicated by the following quotations from Vol. IV of *Geology of Wisconsin:*

In most instances it is perfectly clear, from the nature of the ore filling, that the separation of the beds took place before the implanting of the ores,

[1] *Proceedings of the Washington Academy of Sciences*, Vol. VII (July, 1905), pp. 283–88.

and was not due to any intrusive or crystalline force inherent in the deposit itself. Some, however, instead of being simple sheets between well-defined layers of rock, split and reunite, forming between and about cracked and riven layers of rock, leaving it less clear that all the mechanical action preceded the deposition of the ores. In other cases "dice mineral" and blende impregnate soft beds of rock in sheetlike belts, in which instances it is quite evident that the metaliferous substances displaced the yielding rock in the process of their growth. (P. 468.)

Upon close inspection the soft clayey rock will be found to be thickly inset with scattered crystals of black blende, giving to the fractured rock a beautiful speckled appearance. Looking still closer, it will be seen that the laminæ of the rock curve around the particles of blende, showing that they were displaced by the growth of the blende crystals. (See Fig. 39.) We have in this and the next instance just as clear cases of the forming mineral making room for itself by its own concretionary force, as in some preceding cases it is evident that the receptacle was first formed and the ore subsequently implanted. (P. 474.)

Two other cases are cited, pp. 474, 475, and p. 464.

The first edition of Branner and Newsom's syllabus of economic geology, published in 1895, referred (p. 28; p. 36 of the second edition, 1900) to the enlargement of veins by accretion, under the following heads: "Illustration of needle-ice and crystallization in the soil. The size, form, and structural relations of some geodes shown to be due to enlargement. Evidences of mechanical force of the process. Possible relations to vein enlargement; to brecciation."

That same year, 1895, the fourth edition of Dana's *Manual of Geology* appeared, in which Professor Dana briefly mentions (p. 138) "displacement by intrusion of crystalline material," and cites Worthen upon the splitting and enlargement of crinoids. The paper of Worthen has not been located by the writer. In 1899 Professor Shaler published a paper upon the formation of dikes and veins,[1] in which he uses geodes as illustrations of vein-forming, and remarks (p. 262) that "the pressure of the growing vein . . . . is likely to be even more effective in the group of tabulate deposits in forcing the walls asunder." This is the only instance, with which the writer is acquainted, in which the relation of geode formation to veins has been formally discussed.

In the twentieth annual report of the United States Geological Survey, Part II, published in 1900, Professor I. C. Russell says in regard to the filling of certain brecciated veins (p. 207): "I venture the suggestion that these minerals (quartz and calcite), in crystallizing, have exerted a

[1] *Bulletin of the Geological Society of America*, Vol. X, pp. 253–62.

force analogous to the expansion of water on freezing, which has crowded the rock fragments asunder."

In 1900 also an article by R. A. Daly appeared in the *Journal of Geology* (Vol. VIII, pp. 135-50), in which the author shows the evidence of mechanical force exerted in the formation of calcareous concretions.

Messrs. Becker and Day have now not only demonstrated the mechanical force of growing crystals, but they have been able to measure that force in some instances. The bearing of this work upon the formation of veins is recognized by the authors, for they conclude that

> it thus becomes possible that . . . . great veins have actually been widened to an important extent, perhaps as much as 100 per cent., or even more, by pressure due to this cause. . . . . Again, in a vein where auriferous quartz is being deposited, the growth of crystals may readily extend the space in which successive crops of crystals might grow, so that in certain cases . . . . the deposition of ore might continue almost indefinitely.

The investigation is to be continued, and we shall be greatly disappointed if it does not prove to be one of the most important modern contributions to the theory of vein deposits.

J. C. BRANNER.